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(54) **INTERACTIVE INFECTION VISUALIZATION FOR IMPROVED EXPLOIT DETECTION AND SIGNATURE GENERATION FOR MALWARE AND MALWARE FAMILIES**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,292,580	A	9/1981	Ott et al.
5,175,732	A	12/1992	Hendel et al.

(Continued)

FOREIGN PATENT DOCUMENTS

GB	2439806	A	1/2008
GB	2490431	A	10/2012

(Continued)

OTHER PUBLICATIONS

Adobe Systems Incorporated, "PDF 32000-1:2008, Document management—Portable document format—Part1:PDF 1.7", First Edition, Jul. 1, 2008, 756 pages.

(Continued)

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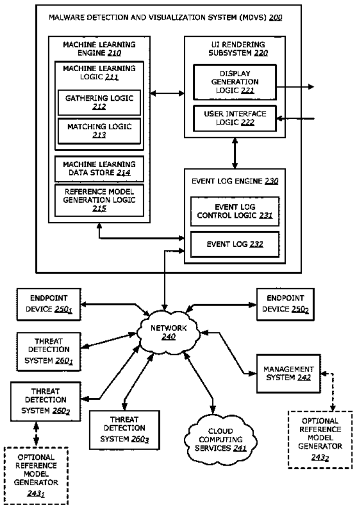
(57) **ABSTRACT**

According to one embodiment, a malware detection and visualization system comprises one or more processors; and a storage module communicatively coupled to the one or more processors, the storage module comprises logic, upon execution by the one or more processors, that accesses a first set of information that comprises (i) information directed to a plurality of observed events and (ii) information directed to one or more relationships that identify an association between different observed events of the plurality of observed events; and generates a reference model based on the first set of information, the reference model comprises at least a first event of the plurality of observed events, a second event of the plurality of observed events, and a first relationship that identifies that the second event is based on the first event, wherein at least one of (i) the plurality of observed events or (ii) the one or more relationships constitutes an anomalous behavior is provided.

52 Claims, 19 Drawing Sheets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(56) **References Cited**

U.S. PATENT DOCUMENTS

5,440,723	A	8/1995	Arnold et al.
5,490,249	A	2/1996	Miller
5,657,473	A	8/1997	Killeen et al.
5,842,002	A	11/1998	Schnurer et al.
5,978,917	A	11/1999	Chi
6,088,803	A	7/2000	Tso et al.
6,094,677	A	7/2000	Capek et al.
6,108,799	A	8/2000	Boulay et al.
6,118,382	A	9/2000	Hibbs et al.
6,269,330	B1	7/2001	Cidon et al.
6,272,641	B1	8/2001	Ji
6,279,113	B1	8/2001	Vaidya
6,298,445	B1	10/2001	Shostack et al.
6,357,008	B1	3/2002	Nachenberg
6,417,774	B1	7/2002	Hibbs et al.
6,424,627	B1	7/2002	S.o slashed.rhaug et al.
6,442,696	B1	8/2002	Wray et al.
6,484,315	B1	11/2002	Ziese
6,487,666	B1	11/2002	Shanklin et al.
6,493,756	B1	12/2002	O'Brien et al.
6,550,012	B1	4/2003	Villa et al.
6,700,497	B2	3/2004	Hibbs et al.
6,775,657	B1	8/2004	Baker
6,831,893	B1	12/2004	Ben Nun et al.
6,832,367	B1	12/2004	Choi et al.
6,895,550	B2	5/2005	Kanchirayappa et al.
6,898,632	B2	5/2005	Gordy et al.
6,907,396	B1	6/2005	Muttik et al.
6,941,348	B2	9/2005	Petry et al.
6,971,097	B1	11/2005	Wallman
6,981,279	B1	12/2005	Arnold et al.
6,995,665	B2	2/2006	Appelt et al.
7,007,107	B1	2/2006	Ivchenko et al.
7,028,179	B2	4/2006	Anderson et al.
7,043,757	B2	5/2006	Hoefelmeyer et al.
7,069,316	B1	6/2006	Gryaznov
7,080,407	B1	7/2006	Zhao et al.
7,080,408	B1	7/2006	Pak et al.
7,093,239	B1	8/2006	van der Made
7,096,498	B2	8/2006	Judge
7,100,201	B2	8/2006	Izatt
7,107,617	B2	9/2006	Hursey et al.
7,159,149	B2	1/2007	Spiegel et al.
7,213,260	B2	5/2007	Judge
7,231,596	B2 *	6/2007	Koren G06F 17/30893 707/E17.12
7,231,667	B2	6/2007	Jordan
7,240,364	B1	7/2007	Branscomb et al.
7,240,368	B1	7/2007	Roesch et al.
7,243,371	B1	7/2007	Kasper et al.
7,249,175	B1	7/2007	Donaldson
7,287,278	B2	10/2007	Liang
7,308,716	B2	12/2007	Danford et al.
7,328,453	B2	2/2008	Merkle, Jr. et al.
7,346,486	B2	3/2008	Ivancic et al.
7,356,736	B2	4/2008	Natvig
7,386,888	B2	6/2008	Liang et al.
7,392,542	B2	6/2008	Bucher
7,418,729	B2	8/2008	Szor
7,428,300	B1	9/2008	Drew et al.
7,441,272	B2	10/2008	Durham et al.
7,448,084	B1	11/2008	Apap et al.
7,458,098	B2	11/2008	Judge et al.
7,464,404	B2	12/2008	Carpenter et al.
7,464,407	B2	12/2008	Nakae et al.
7,467,408	B1	12/2008	O'Toole, Jr.
7,478,428	B1	1/2009	Thomlinson
7,480,773	B1	1/2009	Reed
7,487,543	B2	2/2009	Arnold et al.
7,496,960	B1	2/2009	Chen et al.
7,496,961	B2	2/2009	Zimmer et al.
7,519,990	B1	4/2009	Xie
7,523,493	B2	4/2009	Liang et al.
7,530,104	B1	5/2009	Thrower et al.
7,540,025	B2	5/2009	Tzadikario
7,565,550	B2	7/2009	Liang et al.
7,568,233	B1	7/2009	Szor et al.
7,584,455	B2	9/2009	Ball
7,603,715	B2	10/2009	Costa et al.
7,607,171	B1	10/2009	Marsden et al.
7,639,714	B2	12/2009	Stolfo et al.
7,644,441	B2	1/2010	Schmid et al.
7,657,419	B2	2/2010	van der Made
7,676,841	B2	3/2010	Sobchuk et al.
7,680,703	B1 *	3/2010	Smith G06Q 10/06 705/26.8
7,698,548	B2	4/2010	Shelest et al.
7,707,633	B2	4/2010	Danford et al.
7,712,136	B2	5/2010	Sprosts et al.
7,730,011	B1	6/2010	Deninger et al.
7,739,740	B1	6/2010	Nachenberg et al.
7,779,463	B2	8/2010	Stolfo et al.
7,784,097	B1	8/2010	Stolfo et al.
7,836,502	B1	11/2010	Zhao et al.
7,849,506	B1	12/2010	Dansey et al.
7,854,007	B2	12/2010	Sprosts et al.
7,869,073	B2	1/2011	Oshima
7,877,803	B2	1/2011	Enstone et al.
7,904,959	B2	3/2011	Sidiroglou et al.
7,908,660	B2	3/2011	Bahl
7,930,738	B1	4/2011	Petersen
7,937,761	B1	5/2011	Bennett
7,949,849	B2	5/2011	Lowe et al.
7,996,556	B2	8/2011	Raghavan et al.
7,996,836	B1	8/2011	McCorkendale et al.
7,996,904	B1	8/2011	Chiueh et al.
7,996,905	B2	8/2011	Arnold et al.
8,006,305	B2	8/2011	Aziz
8,010,667	B2	8/2011	Zhang et al.
8,020,206	B2	9/2011	Hubbard et al.
8,028,338	B1	9/2011	Schneider et al.
8,042,184	B1	10/2011	Batenin
8,045,094	B2	10/2011	Teragawa
8,045,458	B2	10/2011	Alperovitch et al.
8,069,484	B2	11/2011	McMillan et al.
8,087,086	B1	12/2011	Lai et al.
8,171,553	B2	5/2012	Aziz et al.
8,176,049	B2	5/2012	Deninger et al.
8,176,480	B1	5/2012	Spertus
8,204,984	B1	6/2012	Aziz et al.
8,214,905	B1	7/2012	Doukhvalov et al.
8,220,055	B1	7/2012	Kennedy
8,225,373	B2	7/2012	Kraemer
8,233,882	B2	7/2012	Rogel
8,234,640	B1	7/2012	Fitzgerald et al.
8,234,709	B2	7/2012	Viljoen et al.
8,239,944	B1	8/2012	Nachenberg et al.
8,260,914	B1	9/2012	Ranjan
8,266,091	B1	9/2012	Gubin et al.
8,286,251	B2	10/2012	Eker et al.
8,291,499	B2	10/2012	Aziz et al.
8,307,435	B1	11/2012	Mann et al.
8,307,443	B2	11/2012	Wang et al.
8,312,545	B2	11/2012	Tuvell et al.
8,321,936	B1	11/2012	Green et al.
8,321,941	B2	11/2012	Tuvell et al.
8,332,571	B1	12/2012	Edwards, Sr.
8,365,286	B2	1/2013	Poston
8,365,297	B1	1/2013	Parshin et al.
8,370,938	B1	2/2013	Daswani et al.
8,370,939	B2	2/2013	Zaitsev et al.
8,375,444	B2	2/2013	Aziz et al.
8,381,299	B2	2/2013	Stolfo et al.
8,402,529	B1	3/2013	Green et al.
8,464,340	B2	6/2013	Ahn et al.
8,479,174	B2	7/2013	Chiriac
8,479,276	B1	7/2013	Vaystikh et al.
8,479,291	B1	7/2013	Bodke
8,510,827	B1	8/2013	Leake et al.

(56) References Cited

U.S. PATENT DOCUMENTS

8,510,828	B1	8/2013	Guo et al.	
8,510,842	B2	8/2013	Amit et al.	
8,516,478	B1	8/2013	Edwards et al.	
8,516,590	B1	8/2013	Ranadive et al.	
8,516,593	B2	8/2013	Aziz	
8,516,594	B2 *	8/2013	Bennett	G06F 21/577 713/188
8,520,015	B2 *	8/2013	Krishna	G06F 9/541 345/522
8,522,348	B2	8/2013	Chen et al.	
8,528,086	B1	9/2013	Aziz	
8,533,824	B2	9/2013	Hutton et al.	
8,539,582	B1	9/2013	Aziz et al.	
8,549,638	B2	10/2013	Aziz	
8,555,391	B1	10/2013	Demir et al.	
8,561,177	B1	10/2013	Aziz et al.	
8,566,946	B1	10/2013	Aziz et al.	
8,584,094	B2	11/2013	Dadhia et al.	
8,584,234	B1	11/2013	Sobel et al.	
8,584,239	B2	11/2013	Aziz et al.	
8,595,834	B2	11/2013	Xie et al.	
8,627,476	B1	1/2014	Satish et al.	
8,635,696	B1	1/2014	Aziz	
8,682,054	B2	3/2014	Xue et al.	
8,682,812	B1	3/2014	Ranjan	
8,689,333	B2	4/2014	Aziz	
8,695,096	B1	4/2014	Zhang	
8,713,631	B1	4/2014	Pavlyushchik	
8,713,681	B2	4/2014	Silberman et al.	
8,726,392	B1	5/2014	McCorkendale et al.	
8,739,280	B2	5/2014	Chess et al.	
8,776,229	B1	7/2014	Aziz	
8,782,792	B1	7/2014	Bodke	
8,787,532	B1	7/2014	Adam	
8,789,172	B2	7/2014	Stolfo et al.	
8,789,178	B2	7/2014	Kejriwal et al.	
8,793,787	B2	7/2014	Ismael et al.	
8,805,947	B1	8/2014	Kuzkin et al.	
8,806,647	B1	8/2014	Daswani et al.	
8,832,829	B2	9/2014	Manni et al.	
8,850,570	B1	9/2014	Ramzan	
8,850,571	B2	9/2014	Staniford et al.	
8,881,234	B2	11/2014	Narasimhan et al.	
8,881,282	B1	11/2014	Aziz et al.	
8,898,788	B1	11/2014	Aziz et al.	
8,935,779	B2	1/2015	Manni et al.	
8,984,638	B1	3/2015	Aziz et al.	
8,990,939	B2	3/2015	Staniford et al.	
8,990,944	B1	3/2015	Singh et al.	
8,997,219	B2	3/2015	Staniford et al.	
9,009,822	B1	4/2015	Ismael et al.	
9,009,823	B1	4/2015	Ismael et al.	
9,027,135	B1	5/2015	Aziz	
9,071,638	B1	6/2015	Aziz et al.	
9,104,867	B1	8/2015	Thioux et al.	
9,106,694	B2	8/2015	Aziz et al.	
9,112,895	B1 *	8/2015	Lin	H04L 63/1416
9,118,714	B1 *	8/2015	Thomson	H04L 63/1441
9,118,715	B2	8/2015	Staniford et al.	
9,195,965	B2 *	11/2015	Sitrick	G06Q 10/101
9,223,972	B1	12/2015	Vincent et al.	
9,239,922	B1 *	1/2016	Zhu	G06F 21/56
9,251,343	B1	2/2016	Vincent et al.	
9,270,689	B1 *	2/2016	Wang	H04L 63/145
9,300,686	B2	3/2016	Pidathala et al.	
9,306,960	B1	4/2016	Aziz	
9,306,974	B1	4/2016	Aziz et al.	
2001/0005889	A1	6/2001	Albrecht	
2001/0047326	A1	11/2001	Broadbent et al.	
2002/0018903	A1	2/2002	Kokubo et al.	
2002/0038430	A1	3/2002	Edwards et al.	
2002/0091819	A1	7/2002	Melchione et al.	
2002/0095607	A1	7/2002	Lin-Hendel	
2002/0116627	A1	8/2002	Tarbotton et al.	
2002/0144156	A1	10/2002	Copeland	
2002/0162015	A1	10/2002	Tang	
2002/0166063	A1	11/2002	Lachman et al.	
2002/0169952	A1	11/2002	DiSanto et al.	
2002/0184528	A1	12/2002	Shevenell et al.	
2002/0188887	A1	12/2002	Largman et al.	
2002/0194490	A1	12/2002	Halperin et al.	
2003/0074578	A1	4/2003	Ford et al.	
2003/0084318	A1	5/2003	Schertz	
2003/0101381	A1	5/2003	Mateev et al.	
2003/0115483	A1	6/2003	Liang	
2003/0188190	A1	10/2003	Aaron et al.	
2003/0191957	A1	10/2003	Hypponen et al.	
2003/0200460	A1	10/2003	Morota et al.	
2003/0212902	A1	11/2003	van der Made	
2003/0229801	A1	12/2003	Kouznetsov et al.	
2003/0237000	A1	12/2003	Denton et al.	
2004/0003323	A1	1/2004	Bennett et al.	
2004/0015712	A1	1/2004	Szor	
2004/0019832	A1	1/2004	Arnold et al.	
2004/0047356	A1	3/2004	Bauer	
2004/0083408	A1	4/2004	Spiegel et al.	
2004/0088581	A1	5/2004	Brawn et al.	
2004/0093513	A1	5/2004	Cantrell et al.	
2004/0111531	A1	6/2004	Staniford et al.	
2004/0117478	A1	6/2004	Triulzi et al.	
2004/0117624	A1	6/2004	Brandt et al.	
2004/0128355	A1	7/2004	Chao et al.	
2004/0143749	A1 *	7/2004	Tajalli	G06F 21/566 726/23
2004/0165588	A1	8/2004	Pandya	
2004/0236963	A1	11/2004	Danford et al.	
2004/0243349	A1	12/2004	Greifeneder et al.	
2004/0243829	A1 *	12/2004	Jordan	G06F 21/566 726/24
2004/0249911	A1	12/2004	Alkhatib et al.	
2004/0255161	A1	12/2004	Cavanaugh	
2004/0268147	A1	12/2004	Wiederin et al.	
2005/0005159	A1	1/2005	Oliphant	
2005/0021740	A1	1/2005	Bar et al.	
2005/0033960	A1	2/2005	Vialen et al.	
2005/0033989	A1	2/2005	Poletto et al.	
2005/0050148	A1	3/2005	Mohammadioun et al.	
2005/0086523	A1	4/2005	Zimmer et al.	
2005/0091513	A1	4/2005	Mitomo et al.	
2005/0091533	A1	4/2005	Omote et al.	
2005/0091652	A1	4/2005	Ross et al.	
2005/0108562	A1	5/2005	Khazan et al.	
2005/0114663	A1	5/2005	Cornell et al.	
2005/0125195	A1	6/2005	Brendel	
2005/0149726	A1	7/2005	Joshi et al.	
2005/0157662	A1	7/2005	Bingham et al.	
2005/0183143	A1 *	8/2005	Anderholm	G06F 11/32 726/22
2005/0201297	A1	9/2005	Peikari	
2005/0203881	A1 *	9/2005	Sakamoto	G06F 21/552
2005/0210533	A1	9/2005	Copeland et al.	
2005/0238005	A1	10/2005	Chen et al.	
2005/0240781	A1	10/2005	Gassoway	
2005/0262562	A1	11/2005	Gassoway	
2005/0265331	A1	12/2005	Stolfo	
2005/0283839	A1	12/2005	Cowburn	
2006/0010495	A1	1/2006	Cohen et al.	
2006/0015416	A1	1/2006	Hoffman et al.	
2006/0015715	A1	1/2006	Anderson	
2006/0015747	A1	1/2006	Van de Ven	
2006/0021029	A1	1/2006	Brickell et al.	
2006/0021054	A1	1/2006	Costa et al.	
2006/0031476	A1	2/2006	Mathes et al.	
2006/0047665	A1	3/2006	Neil	
2006/0070130	A1	3/2006	Costea et al.	
2006/0075496	A1	4/2006	Carpenter et al.	
2006/0095968	A1	5/2006	Portolani et al.	
2006/0101516	A1	5/2006	Sudaharan et al.	
2006/0101517	A1	5/2006	Banzhof et al.	
2006/0117385	A1	6/2006	Mester et al.	
2006/0123477	A1	6/2006	Raghavan et al.	
2006/0143709	A1	6/2006	Brooks et al.	
2006/0150249	A1	7/2006	Gassen et al.	
2006/0161983	A1	7/2006	Cothrell et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2006/0161987	A1	7/2006	Levy-Yurista	
2006/0161989	A1	7/2006	Reshef et al.	
2006/0164199	A1	7/2006	Gilde et al.	
2006/0173992	A1	8/2006	Weber et al.	
2006/0179147	A1	8/2006	Tran et al.	
2006/0184632	A1	8/2006	Marino et al.	
2006/0191010	A1	8/2006	Benjamin	
2006/0195227	A1*	8/2006	Sabe	G05B 13/021 700/245
2006/0221956	A1	10/2006	Narayan et al.	
2006/0236393	A1	10/2006	Kramer et al.	
2006/0242709	A1	10/2006	Seinfeld et al.	
2006/0248519	A1	11/2006	Jaeger et al.	
2006/0248582	A1	11/2006	Panjwani et al.	
2006/0251104	A1	11/2006	Koga	
2006/0288417	A1	12/2006	Bookbinder et al.	
2006/0294589	A1*	12/2006	Achanta	G06F 21/564 726/24
2007/0006288	A1	1/2007	Mayfield et al.	
2007/0006313	A1	1/2007	Porras et al.	
2007/0011174	A1	1/2007	Takaragi et al.	
2007/0016951	A1	1/2007	Piccard et al.	
2007/0033645	A1	2/2007	Jones	
2007/0038943	A1	2/2007	FitzGerald et al.	
2007/0064689	A1	3/2007	Shin et al.	
2007/0074169	A1	3/2007	Chess et al.	
2007/0094730	A1	4/2007	Bhikkaji et al.	
2007/0101435	A1	5/2007	Konanka et al.	
2007/0128855	A1	6/2007	Cho et al.	
2007/0142030	A1	6/2007	Sinha et al.	
2007/0143827	A1	6/2007	Nicodemus et al.	
2007/0156895	A1	7/2007	Vuong	
2007/0157180	A1	7/2007	Tillmann et al.	
2007/0157306	A1	7/2007	Elrod et al.	
2007/0168988	A1	7/2007	Eisner et al.	
2007/0171824	A1	7/2007	Ruello et al.	
2007/0174911	A1*	7/2007	Kronenberg	G06F 21/56 726/22
2007/0174915	A1	7/2007	Gribble et al.	
2007/0192500	A1	8/2007	Lum	
2007/0192858	A1	8/2007	Lum	
2007/0198275	A1	8/2007	Malden et al.	
2007/0208822	A1	9/2007	Wang et al.	
2007/0220607	A1	9/2007	Sprosts et al.	
2007/0240218	A1	10/2007	Tuvell et al.	
2007/0240219	A1	10/2007	Tuvell et al.	
2007/0240220	A1	10/2007	Tuvell et al.	
2007/0240222	A1	10/2007	Tuvell et al.	
2007/0250930	A1	10/2007	Aziz et al.	
2007/0256132	A2	11/2007	Oliphant	
2007/0271446	A1	11/2007	Nakamura	
2008/0005782	A1	1/2008	Aziz	
2008/0028463	A1	1/2008	Dagon et al.	
2008/0032556	A1	2/2008	Schreier	
2008/0040710	A1	2/2008	Chiriac	
2008/0046781	A1	2/2008	Childs et al.	
2008/0066179	A1	3/2008	Liu	
2008/0066180	A1*	3/2008	Repasi	G06F 21/563 726/24
2008/0072326	A1	3/2008	Danford et al.	
2008/0077793	A1	3/2008	Tan et al.	
2008/0080518	A1	4/2008	Hoeflin et al.	
2008/0086720	A1	4/2008	Lekel	
2008/0098476	A1	4/2008	Syversen	
2008/0120722	A1	5/2008	Sima et al.	
2008/0134178	A1	6/2008	Fitzgerald et al.	
2008/0134334	A1	6/2008	Kim et al.	
2008/0141376	A1	6/2008	Clausen et al.	
2008/0184373	A1	7/2008	Traut et al.	
2008/0189787	A1	8/2008	Arnold et al.	
2008/0201778	A1	8/2008	Guo et al.	
2008/0209557	A1	8/2008	Herley et al.	
2008/0215742	A1	9/2008	Goldszmidt et al.	
2008/0222729	A1	9/2008	Chen et al.	
2008/0263665	A1	10/2008	Ma et al.	
2008/0295172	A1	11/2008	Bohacek	
2008/0301810	A1	12/2008	Lehane et al.	
2008/0307524	A1	12/2008	Singh et al.	
2008/0313738	A1	12/2008	Enderby	
2008/0320594	A1	12/2008	Jiang	
2009/0003317	A1	1/2009	Kasralikar et al.	
2009/0007100	A1	1/2009	Field et al.	
2009/0013408	A1	1/2009	Schipka	
2009/0031423	A1	1/2009	Liu et al.	
2009/0036111	A1	2/2009	Danford et al.	
2009/0037835	A1	2/2009	Goldman	
2009/0044024	A1	2/2009	Oberheide et al.	
2009/0044274	A1	2/2009	Budko et al.	
2009/0064332	A1	3/2009	Porras et al.	
2009/0077666	A1	3/2009	Chen et al.	
2009/0083369	A1	3/2009	Marmor	
2009/0083855	A1	3/2009	Apap et al.	
2009/0089879	A1	4/2009	Wang et al.	
2009/0094697	A1	4/2009	Provos et al.	
2009/0113425	A1	4/2009	Ports et al.	
2009/0125976	A1	5/2009	Wassermann et al.	
2009/0126015	A1	5/2009	Monastyrsky et al.	
2009/0126016	A1	5/2009	Sobko et al.	
2009/0133125	A1	5/2009	Choi et al.	
2009/0144823	A1	6/2009	Lamastra et al.	
2009/0158430	A1	6/2009	Borders	
2009/0172815	A1	7/2009	Gu et al.	
2009/0187992	A1	7/2009	Poston	
2009/0193293	A1	7/2009	Stolfo et al.	
2009/0199296	A1	8/2009	Xie et al.	
2009/0228233	A1	9/2009	Anderson et al.	
2009/0241187	A1	9/2009	Troyansky	
2009/0241190	A1	9/2009	Todd et al.	
2009/0265692	A1	10/2009	Godefroid et al.	
2009/0271867	A1	10/2009	Zhang	
2009/0300415	A1	12/2009	Zhang et al.	
2009/0300761	A1	12/2009	Park et al.	
2009/0328185	A1	12/2009	Berg et al.	
2009/0328221	A1	12/2009	Blumfield et al.	
2010/0005146	A1	1/2010	Drako et al.	
2010/0011205	A1	1/2010	McKenna	
2010/0017546	A1	1/2010	Poo et al.	
2010/0031353	A1*	2/2010	Thomas	G06F 11/3604 726/22
2010/0037314	A1	2/2010	Perdisci et al.	
2010/0054278	A1	3/2010	Stolfo et al.	
2010/0115621	A1*	5/2010	Staniford	H04L 63/1416 726/25
2010/0138919	A1*	6/2010	Peng	H04L 29/12009 726/22
2010/0180344	A1	7/2010	Malyshev et al.	
2010/0192223	A1	7/2010	Ismael et al.	
2010/0220863	A1	9/2010	Dupaquis et al.	
2010/0235831	A1	9/2010	Dittmer	
2010/0275263	A1*	10/2010	Bennett	G06F 21/577 726/25
2010/0281539	A1*	11/2010	Burns	H04L 63/1441 726/23
2010/0281541	A1	11/2010	Stolfo et al.	
2010/0281542	A1	11/2010	Stolfo et al.	
2010/0299754	A1	11/2010	Amit et al.	
2010/0306173	A1	12/2010	Frank	
2011/0004737	A1	1/2011	Greenebaum	
2011/0023115	A1*	1/2011	Wright	G06F 21/552 726/22
2011/0023118	A1*	1/2011	Wright	G06F 11/28 726/23
2011/0055907	A1	3/2011	Narasimhan et al.	
2011/0078794	A1	3/2011	Manni et al.	
2011/0093951	A1	4/2011	Aziz	
2011/0099620	A1	4/2011	Stavrou et al.	
2011/0099633	A1	4/2011	Aziz	
2011/0113231	A1	5/2011	Kaminsky	
2011/0145918	A1	6/2011	Jung et al.	
2011/0145920	A1	6/2011	Mahaffey et al.	
2011/0145934	A1	6/2011	Abramovici et al.	
2011/0167493	A1	7/2011	Song et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0167494	A1*	7/2011	Bowen	G06F 21/566 726/24
2011/0173460	A1	7/2011	Ito et al.	
2011/0219449	A1*	9/2011	St. Neitzel	G06F 11/00 726/23
2011/0219450	A1	9/2011	McDougal et al.	
2011/0225624	A1	9/2011	Sawhney et al.	
2011/0225655	A1	9/2011	Niemela et al.	
2011/0247072	A1	10/2011	Staniford et al.	
2011/0265182	A1	10/2011	Peinado et al.	
2011/0289582	A1	11/2011	Kejriwal et al.	
2011/0302587	A1	12/2011	Nishikawa et al.	
2011/0307954	A1	12/2011	Melnik et al.	
2011/0307955	A1	12/2011	Kaplan et al.	
2011/0307956	A1	12/2011	Yermakov et al.	
2011/0314546	A1	12/2011	Aziz et al.	
2011/0320816	A1*	12/2011	Yao	G06F 21/316 713/171
2012/0023593	A1	1/2012	Puder et al.	
2012/0054869	A1	3/2012	Yen et al.	
2012/0066698	A1	3/2012	Yanoo	
2012/0079596	A1	3/2012	Thomas et al.	
2012/0084859	A1	4/2012	Radinsky et al.	
2012/0110667	A1	5/2012	Zubrilin et al.	
2012/0117652	A1	5/2012	Manni et al.	
2012/0121154	A1	5/2012	Xue et al.	
2012/0124426	A1	5/2012	Maybee et al.	
2012/0159519	A1	6/2012	Matsuda	
2012/0174186	A1	7/2012	Aziz et al.	
2012/0174196	A1	7/2012	Bhogavilli et al.	
2012/0174218	A1	7/2012	McCoy et al.	
2012/0198279	A1	8/2012	Schroeder	
2012/0210423	A1	8/2012	Friedrichs et al.	
2012/0222121	A1	8/2012	Staniford et al.	
2012/0255015	A1	10/2012	Sahita et al.	
2012/0255017	A1	10/2012	Sallam	
2012/0260342	A1	10/2012	Dube et al.	
2012/0266244	A1	10/2012	Green et al.	
2012/0278886	A1*	11/2012	Luna	G06F 21/552 726/22
2012/0297489	A1	11/2012	Dequevy	
2012/0330801	A1	12/2012	McDougal et al.	
2012/0331553	A1	12/2012	Aziz et al.	
2013/0014259	A1	1/2013	Gribble et al.	
2013/0019309	A1*	1/2013	Strayer	G06N 5/04 726/23
2013/0036472	A1	2/2013	Aziz	
2013/0047257	A1	2/2013	Aziz	
2013/0074185	A1	3/2013	McDougal et al.	
2013/0086684	A1	4/2013	Mohler	
2013/0097699	A1	4/2013	Balupari et al.	
2013/0097706	A1	4/2013	Titonis et al.	
2013/0111587	A1	5/2013	Goel et al.	
2013/0117852	A1	5/2013	Stute	
2013/0117855	A1	5/2013	Kim et al.	
2013/0139264	A1	5/2013	Brinkley et al.	
2013/0160125	A1	6/2013	Likhachev et al.	
2013/0160127	A1	6/2013	Jeong et al.	
2013/0160130	A1	6/2013	Mendelev et al.	
2013/0160131	A1	6/2013	Madou et al.	
2013/0167236	A1	6/2013	Sick	
2013/0174214	A1	7/2013	Duncan	
2013/0185789	A1	7/2013	Hagiwara et al.	
2013/0185795	A1	7/2013	Winn et al.	
2013/0185798	A1	7/2013	Saunders et al.	
2013/0191915	A1	7/2013	Antonakakis et al.	
2013/0196649	A1	8/2013	Paddon et al.	
2013/0227691	A1	8/2013	Aziz et al.	
2013/0246370	A1	9/2013	Bartram et al.	
2013/0263260	A1	10/2013	Mahaffey et al.	
2013/0291109	A1	10/2013	Staniford et al.	
2013/0298243	A1	11/2013	Kumar et al.	
2014/0013434	A1*	1/2014	Ranum	H04L 63/145 726/24
2014/0053260	A1	2/2014	Gupta et al.	
2014/0053261	A1*	2/2014	Gupta	G06F 21/55 726/22
2014/0090056	A1*	3/2014	Manadhata	G06F 21/552 726/23
2014/0122391	A1	5/2014	Mugan et al.	
2014/0130158	A1	5/2014	Wang et al.	
2014/0137180	A1	5/2014	Lukacs et al.	
2014/0150100	A1*	5/2014	Gupta	G06F 21/316 726/22
2014/0165140	A1*	6/2014	Singla	G06F 11/3006 726/1
2014/0169762	A1	6/2014	Ryu	
2014/0179360	A1	6/2014	Jackson et al.	
2014/0223553	A1*	8/2014	Gupta	G06F 21/52 726/22
2014/0328204	A1	11/2014	Klotsche et al.	
2014/0337836	A1	11/2014	Ismael	
2014/0351935	A1	11/2014	Shao et al.	
2015/0096025	A1	4/2015	Ismael	
2015/0135262	A1*	5/2015	Porat	G06F 21/552 726/1
2015/0172300	A1*	6/2015	Cochenour	H04L 63/1425 726/23
2015/0186645	A1	7/2015	Aziz et al.	
2015/0372980	A1	12/2015	Eyada	

FOREIGN PATENT DOCUMENTS

WO	02/23805	A2	3/2002
WO	02/006928	A2	8/2003
WO	2007117636	A2	10/2007
WO	2008041950	A2	4/2008
WO	2011084431	A2	7/2011
WO	2011/112348	A1	9/2011
WO	2012/075336	A1	6/2012
WO	2013/067505	A1	5/2013

OTHER PUBLICATIONS

Apostolopoulos, George; hassapis, Constantinos; "V-eM: A cluster of Virtual Machines for Robust, Detailed, and High-Performance Network Emulation", 14th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems, Sep. 11-14, 2006, pp. 117-126.

Clark, John, Sylvian Leblanc,and Scott Knight. "Risks associated with usb hardware trojan devices used by insiders." Systems Conference (SysCon), 2011 IEEE International. IEEE, 2011.

FireEye Malware Analysis & Exchange Network, Malware Protection System, FireEye Inc., 2010.

FireEye Malware Analysis, Modern Malware Forensics, FireEye Inc., 2010.

FireEye v.6.0 Security Target, pp. 1-35, Version 1.1, FireEye Inc., May 2011.

Gibler, Clint, et al. AndroidLeaks: automatically detecting potential privacy leaks in android applications on a large scale. Springer Berlin Heidelberg, 2012.

Gregg Keizer: "Microsoft's HoneyMonkeys Show Patching Windows Works", Aug. 8, 2005, XP055143386, Retrieved from the Internet: URL:https://web.archive.org/web/20121022220617/http://www.informationweek- .com/microsofts-honeymonkeys-show-patching-wi/167600716 [retrieved on Sep. 29, 2014].

Heng Yin et al, Panorama: Capturing System-Wide Information Flow for Malware Detection and Analysis, Research Showcase @ CMU, Carnegie Mellon University, 2007.

Idika et al., A-Survey-of-Malware-Detection-Techniques, Feb. 2, 2007, Department of Computer Science, Purdue University.

Isohara, Takamasa, Keisuke Takemori, and Ayumu Kubota. "Kernel-based behavior analysis for android malware detection." Computational intelligence and Security (CIS), 2011 Seventh International Conference on. IEEE, 2011.

Kevin A Roundy et al: "Hybrid Analysis and Control of Malware", Sep. 15, 2010, Recent Advances in Intrusion Detection, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 317-338, XP019150454 ISBN:978-3-642-15511-6.

(56) References Cited

OTHER PUBLICATIONS

Leading Colleges Select FireEye to Stop Malware-Related Data Breaches, FireEye Inc., 2009.

Li et al., A VMM-Based System Call Interposition Framework for Program Monitoring, Dec. 2010, IEEE 16th International Conference on Parallel and Distributed Systems, pp. 706-711.

Lindorfer, Martina, Clemens Kolbitsch, and Paolo Milani Comparetti. "Detecting environment-sensitive malware." Recent Advances in Intrusion Detection. Springer Berlin Heidelberg, 2011.

Mori, Detecting Unknown Computer Viruses, 2004, Springer-Verlag Berlin Heidelberg.

Oberheide et al., CloudAV.sub.—N-Version Antivirus in the Network Cloud, 17th USENIX Security Symposium USENIX Security '08 Jul. 28-Aug. 1, 2008 San Jose, CA.

Wahid et al., Characterising the Evolution in Scanning Activity of Suspicious Hosts, Oct. 2009, Third International Conference on Network and System Security, pp. 344-350.

Yuhei Kawakoya et al: "Memory behavior-based automatic malware unpacking in stealth debugging environment", Malicious and Unwanted Software (Malware), 2010 5th International Conference on, IEEE, Piscataway, NJ, USA, Oct. 19, 2010, pp. 39-46, XP031833827, ISBN:978-1-4244-8-9353-1.

Zhang et al., The Effects of Threading, Infection Time, and Multiple-Attacker Collaboration on Malware Propagation, Sep. 2009, IEEE 28th International Symposium on Reliable Distributed Systems, pp. 73-82.

U.S. Pat. No. 8,171,553 filed Apr. 20, 2006, Inter Parties Review Decision dated Jul. 10, 2015.

U.S. Pat. No. 8,291,499 filed Mar. 16, 2012, Inter Parties Review Decision dated Jul. 10, 2015.

Venezia, Paul , "NetDetector Captures Intrusions", InfoWorld Issue 27, ("Venezia"), (Jul. 14, 2003).

Whyte, et al., "DNS-Based Detection of Scanning Works in an Enterprise Network", Proceedings of the 12th Annual Network and Distributed System Security Symposium, (Feb. 2005), 15 pages.

Williamson, Matthew M., "Throttling Viruses: Restricting Propagation to Defeat Malicious Mobile Code", ACSAC Conference, Las Vegas, NV, USA, (Dec. 2002), pp. 1-9.

"Network Security: NetDetector—Network Intrusion Forensic System (NIFS) Whitepaper", ("NetDetector Whitepaper"), (2003).

"Packet", Microsoft Computer Dictionary, Microsoft Press, (Mar. 2002), 1 page.

"When Virtual is Better Than Real", IEEEXplore Digital Library, available at, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumbe- r=990073, (Dec. 7, 2013).

Abdullah, et al., Visualizing Network Data for Intrusion Detection, 2005 IEEE Workshop on Information Assurance and Security, pp. 100-108.

Adetoye, Adedayo , et al., "Network Intrusion Detection & Response System", ("Adetoye"), (Sep. 2003).

AltaVista Advanced Search Results. "attack vector identifier". Http://www.altavista.com/web/results?Itag=ody&pg=aq&aqmode=aqa=Event+Orch- estrator . . . , (Accessed on Sep. 15, 2009).

AltaVista Advanced Search Results. "Event Orchestrator". Http://www.altavista.com/web/results?Itag=ody&pg=aq&aqmode=aqa=Event+Orch- esrator . . . , (Accessed on Sep. 3, 2009).

Aura, Tuomas, "Scanning electronic documents for personally identifiable information", Proceedings of the 5th ACM workshop on Privacy in electronic society. ACM, 2006.

Baecher, "The Nepenthes Platform: An Efficient Approach to collect Malware", Springer-verlag Berlin Heidelberg, (2006), pp. 165-184.

Baldi, Mario; Risso, Fulvio; "A Framework for Rapid Development and Portable Execution of Packet-Handling Applications", 5th IEEE International Symposium Processing and Information Technology, Dec. 21, 2005, pp. 233-238.

Bayer, et al., "Dynamic Analysis of Malicious Code", J Comput Virol, Springer-Verlag, France., (2006), pp. 67-77.

Boubalos, Chris , "extracting syslog data out of raw pcap dumps, seclists.org, Honeypots mailing list archives", available at http://seclists.org/honeypots/2003/q2/319 ("Boubalos"), (Jun. 5, 2003).

Chaudet, C. , et al., "Optimal Positioning of Active and Passive Monitoring Devices", International Conference on Emerging Networking Experiments and Technologies, Proceedings of the 2005 ACM Conference on Emerging Network Experiment and Technology, CoNEXT '05, Toulousse, France, (Oct. 2005), pp. 71-82.

Chen, P. M. and Noble, B. D., "When Virtual is Better Than Real, Department of Electrical Engineering and Computer Science", University of Michigan ("Chen").

Cisco "Intrusion Prevention for the Cisco ASA 5500-x Series" Data Sheet (2012).

Cisco, Configuring the Catalyst Switched Port Analyzer (SPAN) ("Cisco"), (1992-2003).

Cohen, M.I. , "PyFlag—An advanced network forensic framework", Digital investigation 5, Elsevier, (2008), pp. S112-S120.

Costa, M. , et al., "Vigilante: End-to-End Containment of Internet Worms", SOSP '05, Association for Computing Machinery, Inc., Brighton U.K., (Oct. 23-26, 2005).

Crandall, J.R. , et al., "Minos:Control Data Attack Prevention Orthogonal to Memory Model", 37th International Symposium on Microarchitecture, Portland, Oregon, (Dec. 2004).

Deutsch, P. , "Zlib compressed data format specification version 3.3" RFC 1950, (1996).

Distler, "Malware Analysis: An Introduction", SANS Institute InfoSec Reading Room, SANS Institute, (2007).

Dunlap, George W. , et al., "ReVirt: Enabling Intrusion Analysis through Virtual-Machine Logging and Replay", Proceeding of the 5th Symposium on Operating Systems Design and Implementation, USENIX Association, ("Dunlap"), (Dec. 9, 2002).

Excerpt regarding First Printing Date for Merike Kaeo, Designing Network Security ("Kaeo"), (2005).

Filiol, Eric , et al., "Combinatorial Optimisation of Worm Propagation on an Unknown Network", International Journal of Computer Science 2.2 (2007).

Goel, et al., Reconstructing System State for Intrusion Analysis, Apr. 2008 SIGOPS Operating Systems Review, vol. 42 Issue 3, pp. 21-28.

Hjelmvik, Erik , "Passive Network Security Analysis with NetworkMiner", (IN)Secure, Issue 18, (Oct. 2008), pp. 1-100.

IEEE Xplore Digital Library Sear Results for "detection of unknown computer worms". Http//ieeexplore.ieee.org/searchresult.jsp?SortField=Score&SortOrder=desc- &ResultC . . . , (Accessed on Aug. 28, 2009).

Kaeo, Merike , "Designing Network Security", ("Kaeo"), (Nov. 2003).

Kim, H. , et al., "Autograph: Toward Automated, Distributed Worm Signature Detection", Proceedings of the 13th Usenix Security Symposium (Security 2004), San Diego, (Aug. 2004), pp. 271-286.

King, Samuel T., et al., "Operating System Support for Virtual Machines", ("King").

Krasnyansky, Max , et al., Universal TUN/TAP driver, available at https://www.kernel.org/doc/Documentation/networking/tuntap.txt (2002) ("Krasnyansky").

Kreibich, C. , et al., "Honeycomb-Creating Intrusion Detection Signatures Using Honeypots", 2nd Workshop on Hot Topics in Networks (HotNets-11), Boston, USA, (2003).

Kristoff, J. , "Botnets, Detection and Mitigation: DNS-Based Techniques", NU Security Day, (2005), 23 pages.

Liljenstam, Michael , et al., "Simulating Realistic Network Traffic for Worm Warning System Design and Testing", Institute for Security Technology studies, Dartmouth College ("Liljenstam"), (Oct. 27, 2003).

Lok Kwong et al: "DroidScope: Seamlessly Reconstructing the OS and Dalvik Semantic Views for Dynamic Android Malware Analysis", Aug. 10, 2012, XP055158513, Retrieved from the Internet: URL:https://www.usenix.org/system/files/conference/usenixsecurity12/sec12- -final107.pdf [retrieved on Dec. 15, 2014].

Marchette, David J., "Computer Intrusion Detection and Network Monitoring: A Statistical Viewpoint", ("Marchette"), (2001).

Margolis, P.E. , "Random House Webster's 'Computer & Internet Dictionary 3rd Edition'", ISBN 0375703519, (Dec. 1998).

(56) **References Cited**

OTHER PUBLICATIONS

Moore, D. , et al., "Internet Quarantine: Requirements for Containing Self-Propagating Code", INFOCOM, vol. 3, (Mar. 30-Apr. 3, 2003), pp. 1901-1910.
Morales, Jose A., et al., ""Analyzing and exploiting network behaviors of malware."", Security and Privacy in Communication Networks. Springer Berlin Heidelberg, 2010. 20-34.
Natvig, Kurt , "SANDBOXII: Internet", Virus Bulletin Conference, ("Natvig"), (Sep. 2002).
NetBIOS Working Group. Protocol Standard for a NetBIOS Service on a TCP/UDP transport: Concepts and Methods. STD 19, RFC 1001, Mar. 1987.
Newsome, J. , et al., "Dynamic Taint Analysis for Automatic Detection, Analysis, and Signature Generation of Exploits on Commodity Software", In Proceedings of the 12th Annual Network and Distributed System Security, Symposium (NDSS '05), (Feb. 2005).
Newsome, J. , et al., "Polygraph: Automatically Generating Signatures for Polymorphic Worms", In Proceedings of the IEEE Symposium on Security and Privacy, (May 2005).
Nojiri, D. , et al., "Cooperation Response Strategies for Large Scale Attack Mitigation", DARPA Information Survivability Conference and Exposition, vol. 1, (Apr. 22-24, 2003), pp. 293-302.
Reiner Sailer, Enriquillo Valdez, Trent Jaeger, Roonald Perez, Leendert van Doom, John Linwood Griffin, Stefan Berger., sHype: Secure Hypervisor Appraoch to Trusted Virtualized Systems (Feb. 2, 2005) ("Sailer").
Silicon Defense, "Worm Containment in the Internal Network", (Mar. 2003), pp. 1-25.
Singh, S. , et al., "Automated Worm Fingerprinting", Proceedings of the ACM/USENIX Symposium on Operating System Design and Implementation, San Francisco, California, (Dec. 2004).
Spitzner, Lance , "Honeypots: Tracking Hackers", ("Spizner"), (Sep. 17, 2002).
The Sniffers's Guide to Raw Traffic available at: yuba.stanford.edu/.about.casado/pcap/section1.html, (Jan. 6, 2014).
Thomas H. Ptacek, and Timothy N. Newsham , "Insertion, Evasion, and Denial of Service: Eluding Network Intrusion Detection", Secure Networks, ("Ptacek"), (Jan. 1998).

* cited by examiner

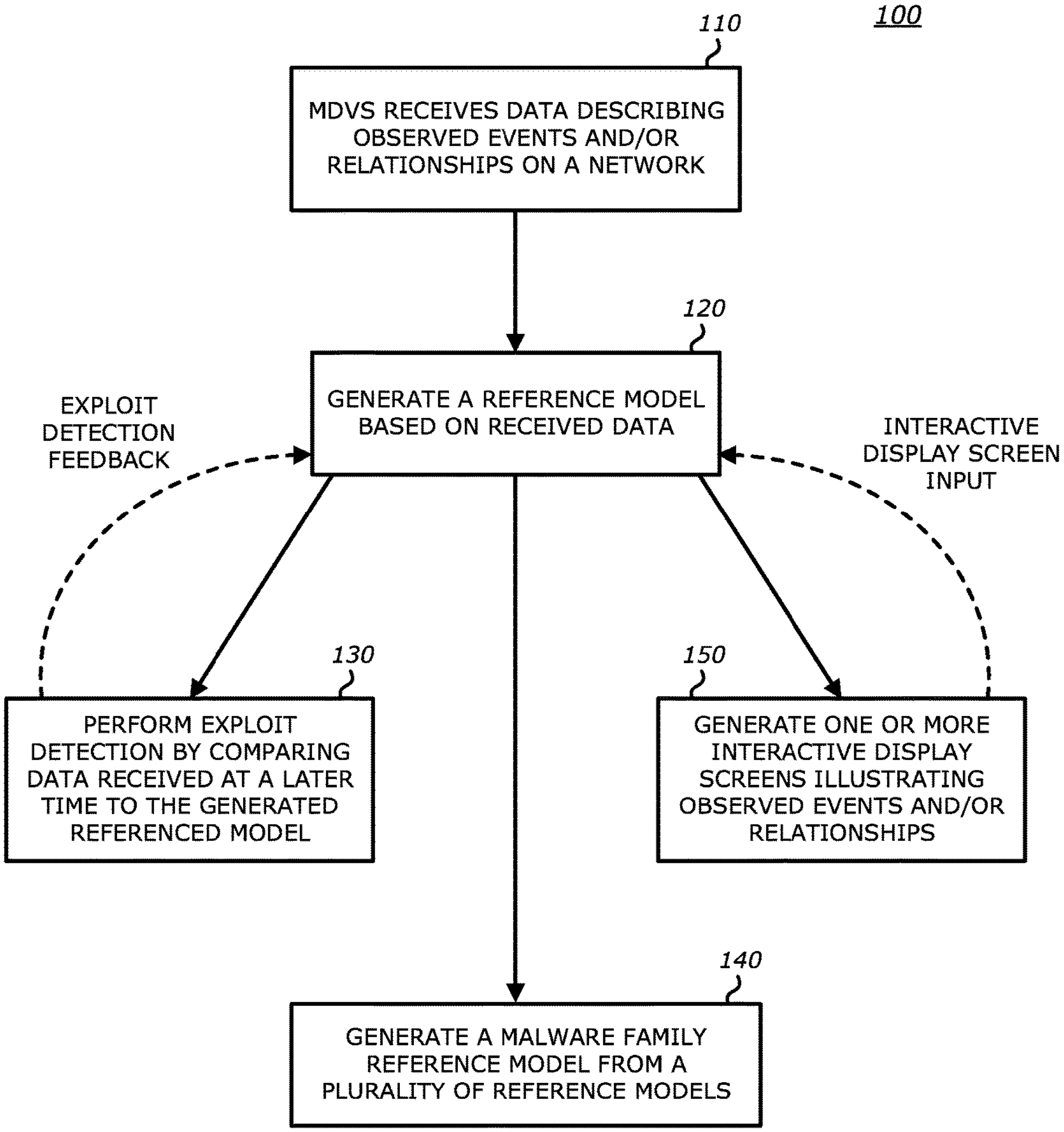

100
110
MDVS RECEIVES DATA DESCRIBING OBSERVED EVENTS AND/OR RELATIONSHIPS ON A NETWORK
120
GENERATE A REFERENCE MODEL BASED ON RECEIVED DATA
EXPLOIT DETECTION FEEDBACK
INTERACTIVE DISPLAY SCREEN INPUT
130
PERFORM EXPLOIT DETECTION BY COMPARING DATA RECEIVED AT A LATER TIME TO THE GENERATED REFERENCED MODEL
150
GENERATE ONE OR MORE INTERACTIVE DISPLAY SCREENS ILLUSTRATING OBSERVED EVENTS AND/OR RELATIONSHIPS
140
GENERATE A MALWARE FAMILY REFERENCE MODEL FROM A PLURALITY OF REFERENCE MODELS

FIG. 1

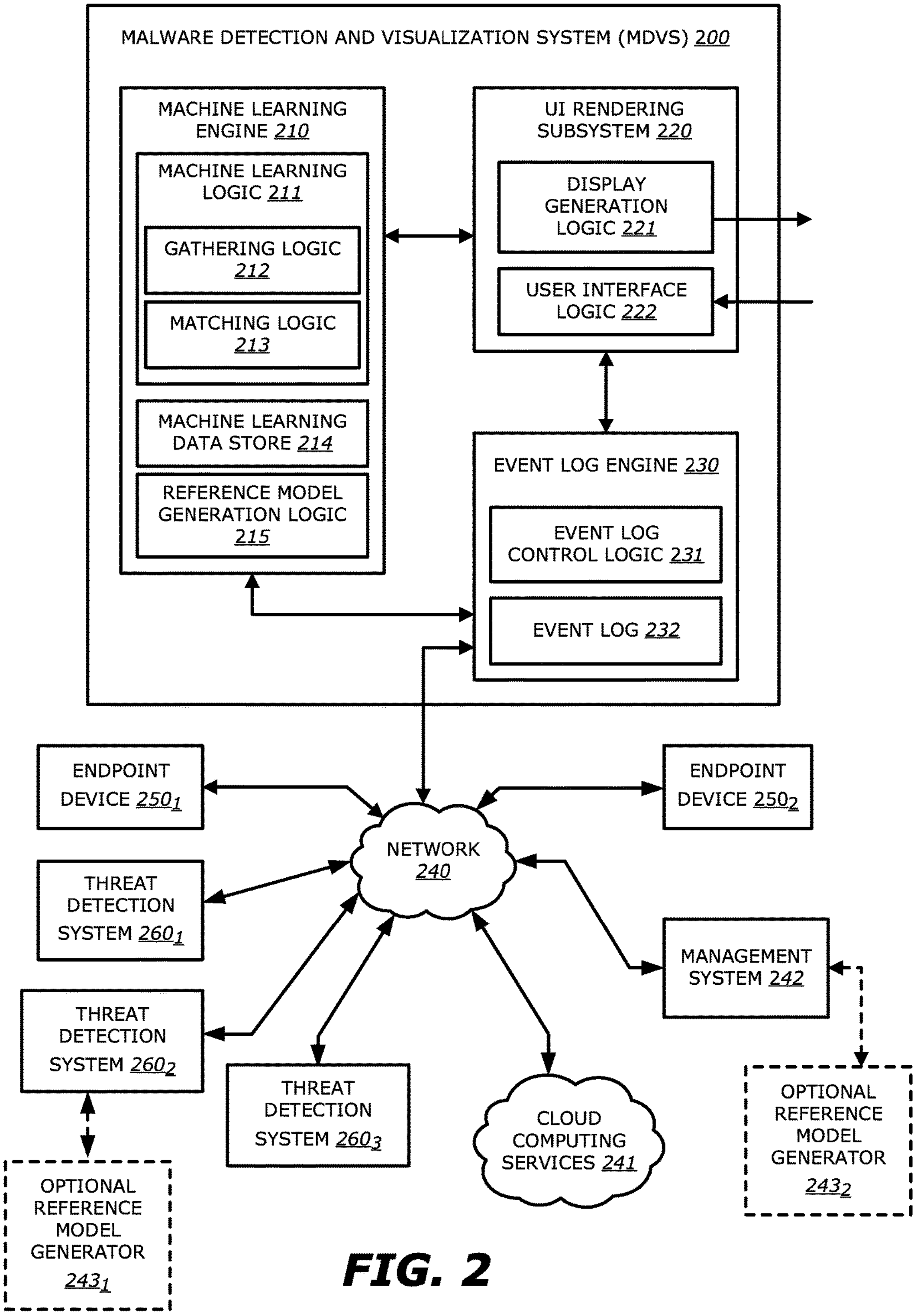

MALWARE DETECTION AND VISUALIZATION SYSTEM (MDVS) 200
MACHINE LEARNING ENGINE 210
MACHINE LEARNING LOGIC 211
GATHERING LOGIC 212
MATCHING LOGIC 213
MACHINE LEARNING DATA STORE 214
REFERENCE MODEL GENERATION LOGIC 215
UI RENDERING SUBSYSTEM 220
DISPLAY GENERATION LOGIC 221
USER INTERFACE LOGIC 222
EVENT LOG ENGINE 230
EVENT LOG CONTROL LOGIC 231
EVENT LOG 232
ENDPOINT DEVICE 250_1
ENDPOINT DEVICE 250_2
NETWORK 240
THREAT DETECTION SYSTEM 260_1
THREAT DETECTION SYSTEM 260_2
THREAT DETECTION SYSTEM 260_3
CLOUD COMPUTING SERVICES 241
MANAGEMENT SYSTEM 242
OPTIONAL REFERENCE MODEL GENERATOR 243_1
OPTIONAL REFERENCE MODEL GENERATOR 243_2

FIG. 2

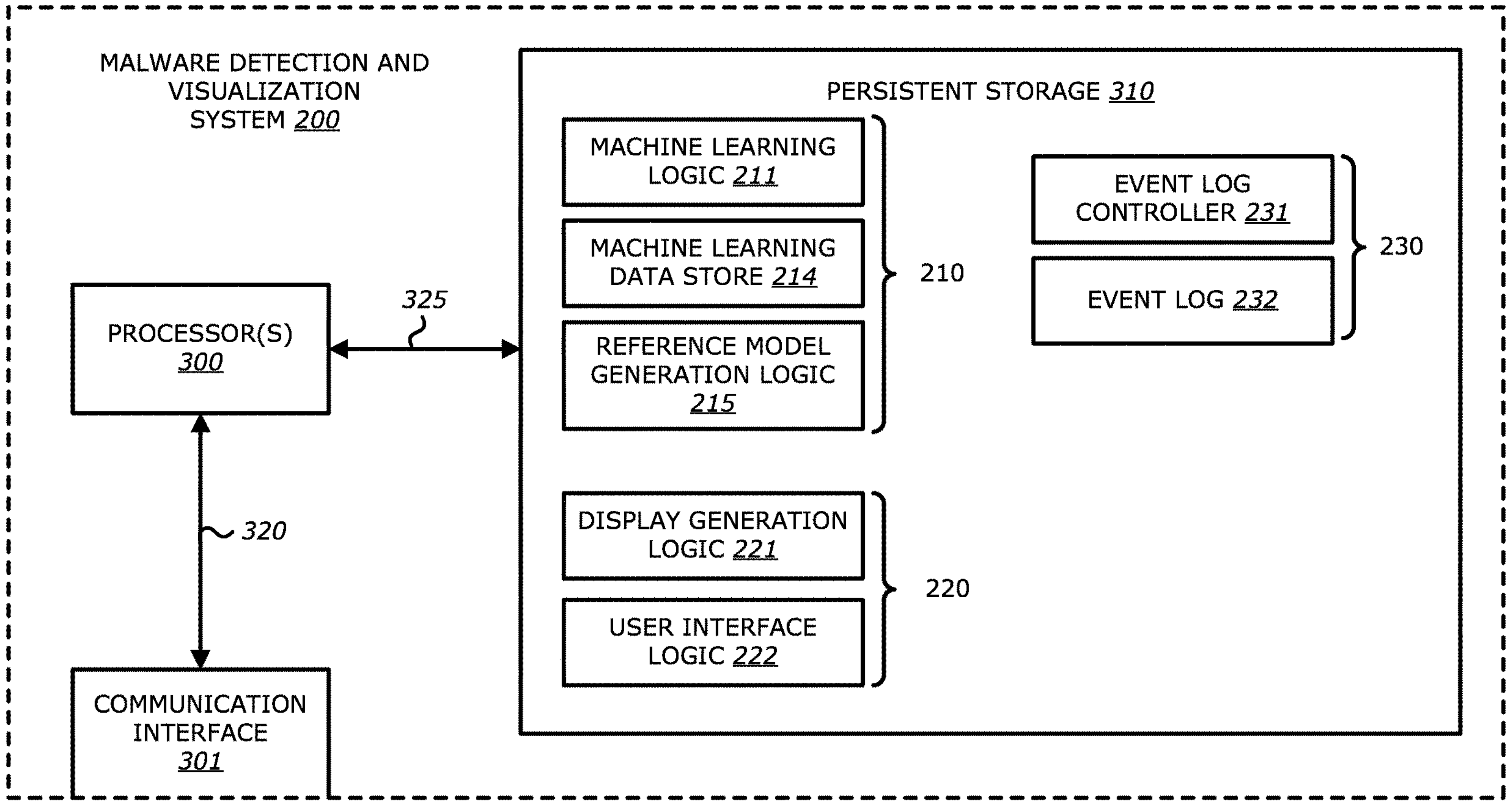
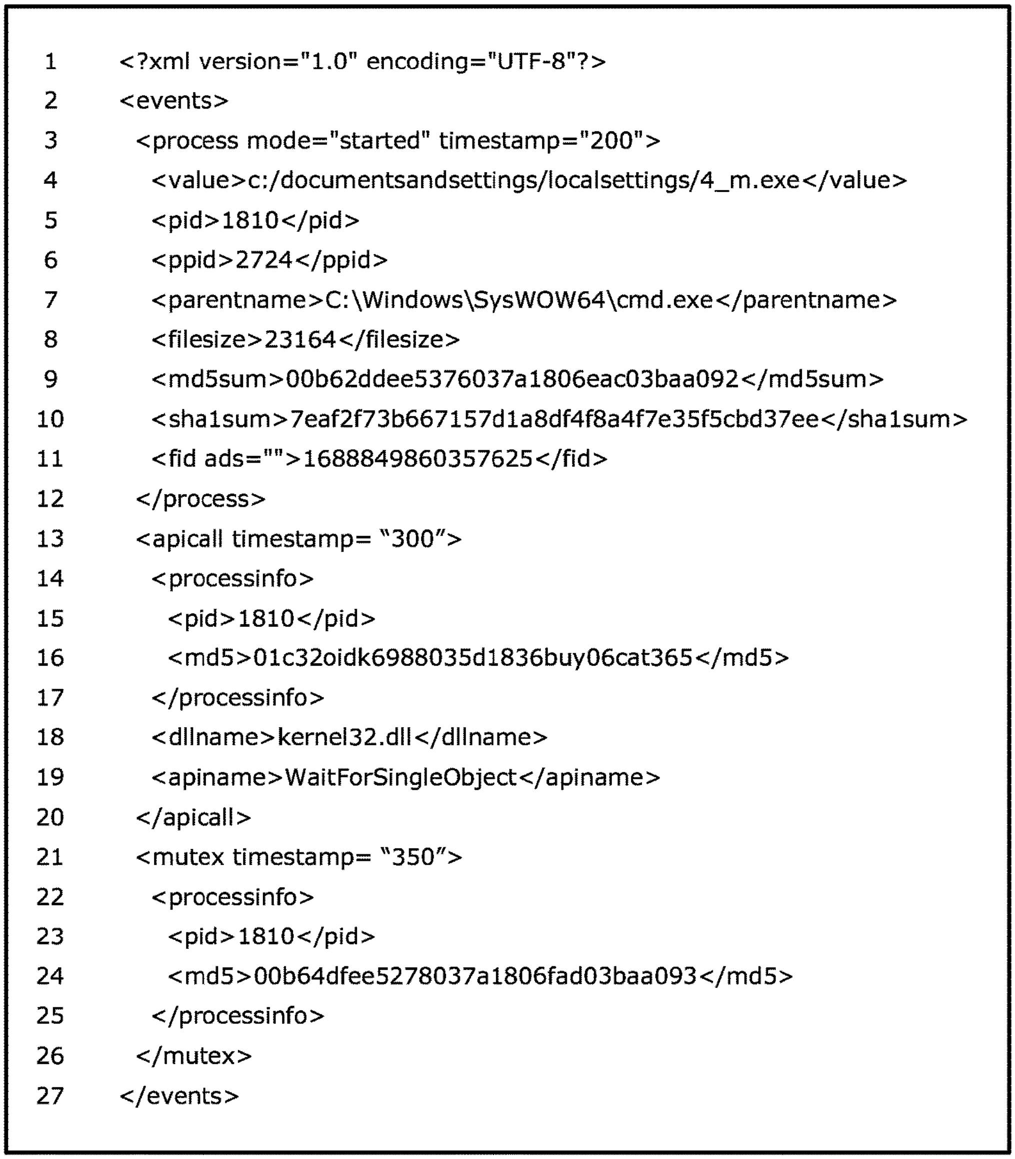
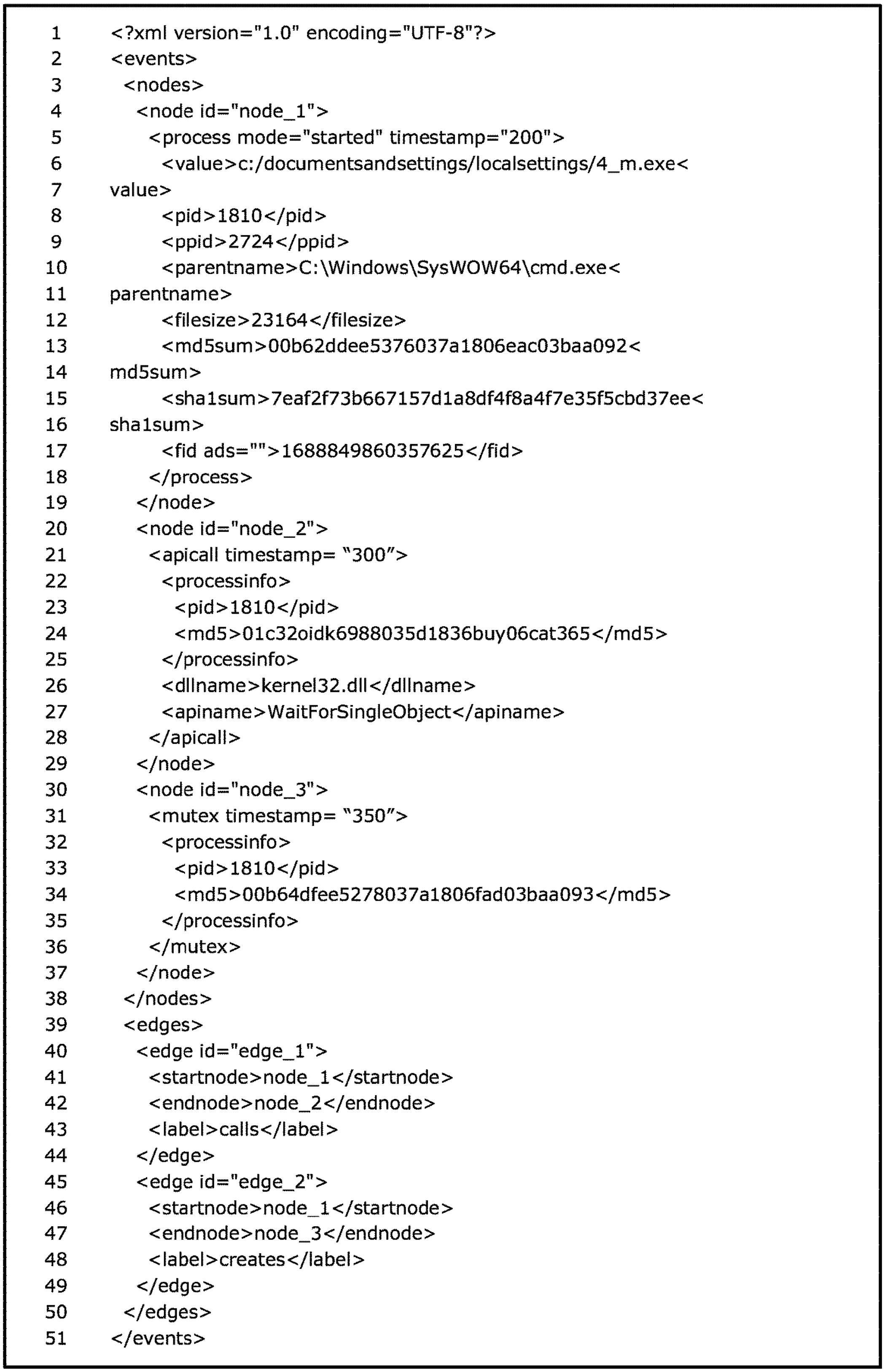

MALWARE DETECTION AND VISUALIZATION SYSTEM 200
PROCESSOR(S) 300
COMMUNICATION INTERFACE 301
320
325
PERSISTENT STORAGE 310
MACHINE LEARNING LOGIC 211
MACHINE LEARNING DATA STORE 214
REFERENCE MODEL GENERATION LOGIC 215
210
EVENT LOG CONTROLLER 231
EVENT LOG 232
230
DISPLAY GENERATION LOGIC 221
USER INTERFACE LOGIC 222
220

FIG. 3



```
<?xml version="1.0" encoding="UTF-8"?>
<events>
  <process mode="started" timestamp="200">
    <value>c:/documentsandsettings/localsettings/4_m.exe</value>
    <pid>1810</pid>
    <ppid>2724</ppid>
    <parentname>C:\Windows\SysWOW64\cmd.exe</parentname>
    <filesize>23164</filesize>
    <md5sum>00b62ddee5376037a1806eac03baa092</md5sum>
    <sha1sum>7eaf2f73b667157d1a8df4f8a4f7e35f5cbd37ee</sha1sum>
    <fid ads="">1688849860357625</fid>
  </process>
  <apicall timestamp= “300”>
    <processinfo>
      <pid>1810</pid>
      <md5>01c32oidk6988035d1836buy06cat365</md5>
    </processinfo>
    <dllname>kernel32.dll</dllname>
    <apiname>WaitForSingleObject</apiname>
  </apicall>
  <mutex timestamp= “350”>
    <processinfo>
      <pid>1810</pid>
      <md5>00b64dfee5278037a1806fad03baa093</md5>
    </processinfo>
  </mutex>
</events>
```

FIG. 4



```
<?xml version="1.0" encoding="UTF-8"?>
<events>
  <nodes>
    <node id="node_1">
      <process mode="started" timestamp="200">
        <value>c:/documentsandsettings/localsettings/4_m.exe<
value>
        <pid>1810</pid>
        <ppid>2724</ppid>
        <parentname>C:\Windows\SysWOW64\cmd.exe<
parentname>
        <filesize>23164</filesize>
        <md5sum>00b62ddee5376037a1806eac03baa092<
md5sum>
        <sha1sum>7eaf2f73b667157d1a8df4f8a4f7e35f5cbd37ee<
sha1sum>
        <fid ads="">1688849860357625</fid>
      </process>
    </node>
    <node id="node_2">
      <apicall timestamp= “300”>
        <processinfo>
          <pid>1810</pid>
          <md5>01c32oidk6988035d1836buy06cat365</md5>
        </processinfo>
        <dllname>kernel32.dll</dllname>
        <apiname>WaitForSingleObject</apiname>
      </apicall>
    </node>
    <node id="node_3">
      <mutex timestamp= “350”>
        <processinfo>
          <pid>1810</pid>
          <md5>00b64dfee5278037a1806fad03baa093</md5>
        </processinfo>
      </mutex>
    </node>
  </nodes>
  <edges>
    <edge id="edge_1">
      <startnode>node_1</startnode>
      <endnode>node_2</endnode>
      <label>calls</label>
    </edge>
    <edge id="edge_2">
      <startnode>node_1</startnode>
      <endnode>node_3</endnode>
      <label>creates</label>
    </edge>
  </edges>
</events>
```

FIG. 5

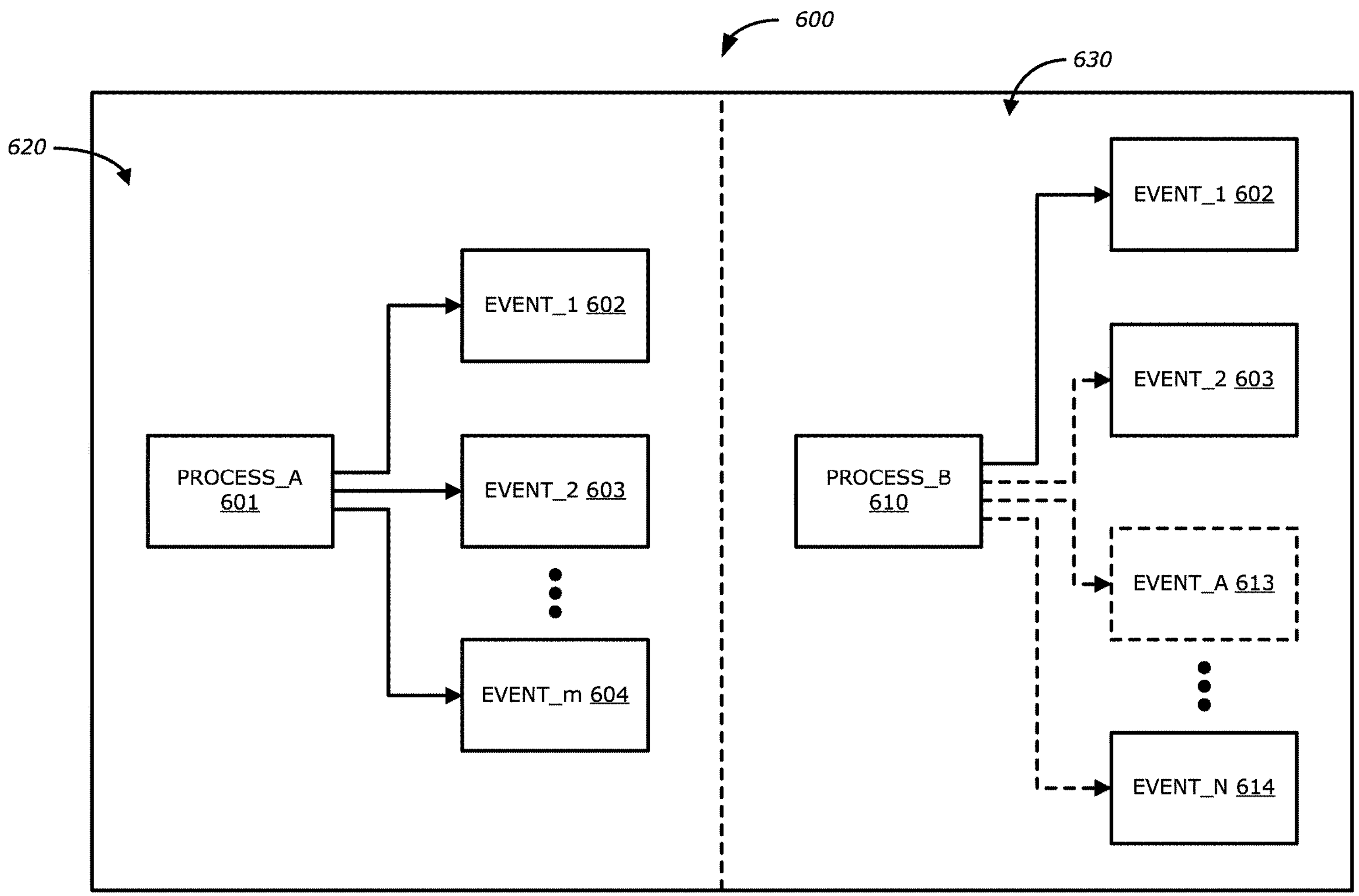

600
620
630
PROCESS_A 601
EVENT_1 602
EVENT_2 603
EVENT_m 604
PROCESS_B 610
EVENT_1 602
EVENT_2 603
EVENT_A 613
EVENT_N 614

FIG. 6

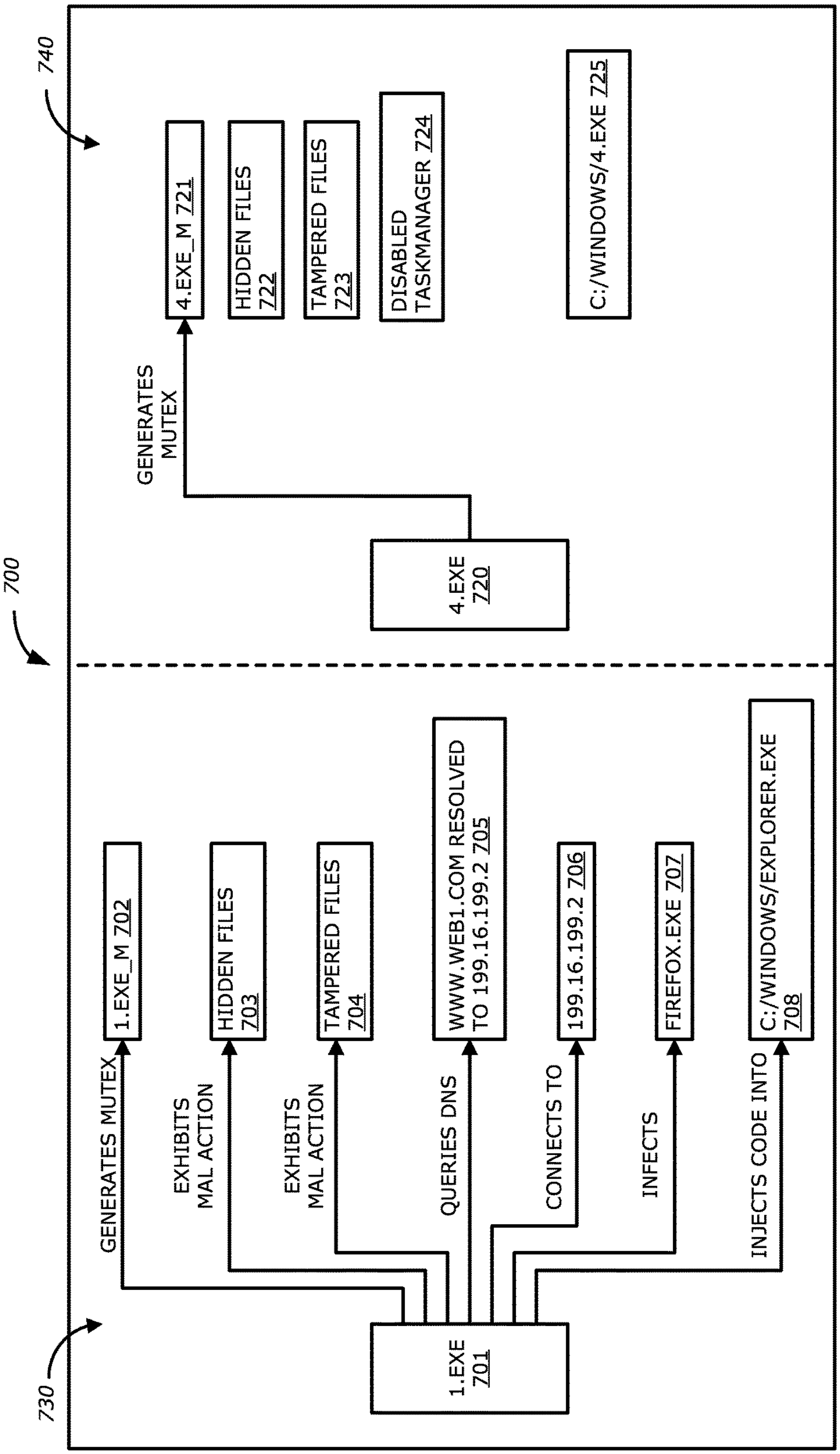

700
730
1.EXE 701
GENERATES MUTEX
1.EXE_M 702
EXHIBITS MAL ACTION
HIDDEN FILES 703
EXHIBITS MAL ACTION
TAMPERED FILES 704
QUERIES DNS
WWW.WEB1.COM RESOLVED TO 199.16.199.2 705
CONNECTS TO
199.16.199.2 706
INFECTS
FIREFOX.EXE 707
INJECTS CODE INTO
C:/WINDOWS/EXPLORER.EXE 708
740
4.EXE 720
GENERATES MUTEX
4.EXE_M 721
HIDDEN FILES 722
TAMPERED FILES 723
DISABLED TASKMANAGER 724
C:/WINDOWS/4.EXE 725

FIG. 7A

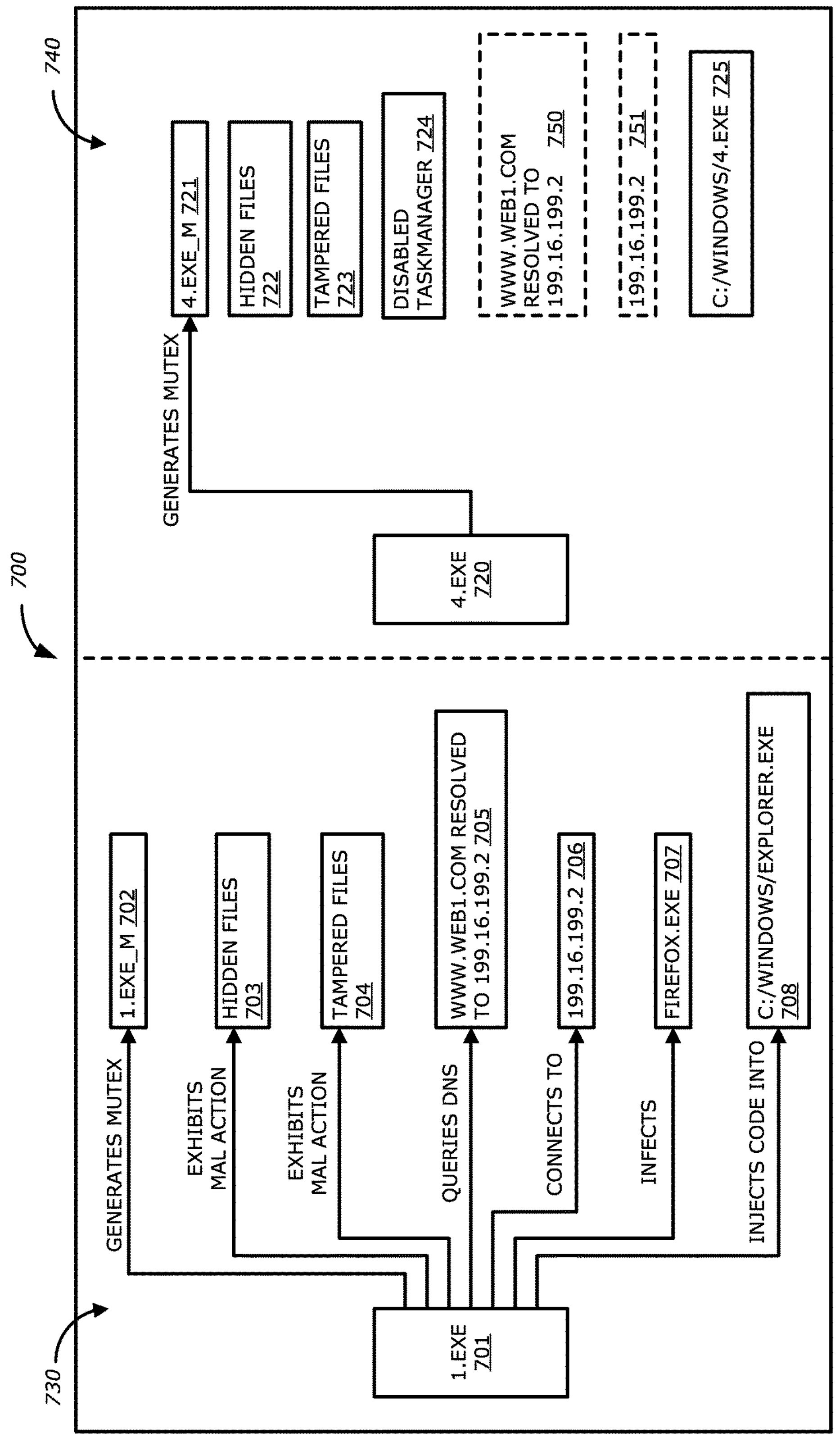

700
730
1.EXE 701
GENERATES MUTEX
1.EXE_M 702
EXHIBITS MAL ACTION
HIDDEN FILES 703
EXHIBITS MAL ACTION
TAMPERED FILES 704
QUERIES DNS
WWW.WEB1.COM RESOLVED TO 199.16.199.2 705
CONNECTS TO
199.16.199.2 706
INFECTS
FIREFOX.EXE 707
INJECTS CODE INTO
C:/WINDOWS/EXPLORER.EXE 708
740
4.EXE 720
GENERATES MUTEX
4.EXE_M 721
HIDDEN FILES 722
TAMPERED FILES 723
DISABLED TASKMANAGER 724
WWW.WEB1.COM RESOLVED TO 199.16.199.2 750
199.16.199.2 751
C:/WINDOWS/4.EXE 725

FIG. 7B

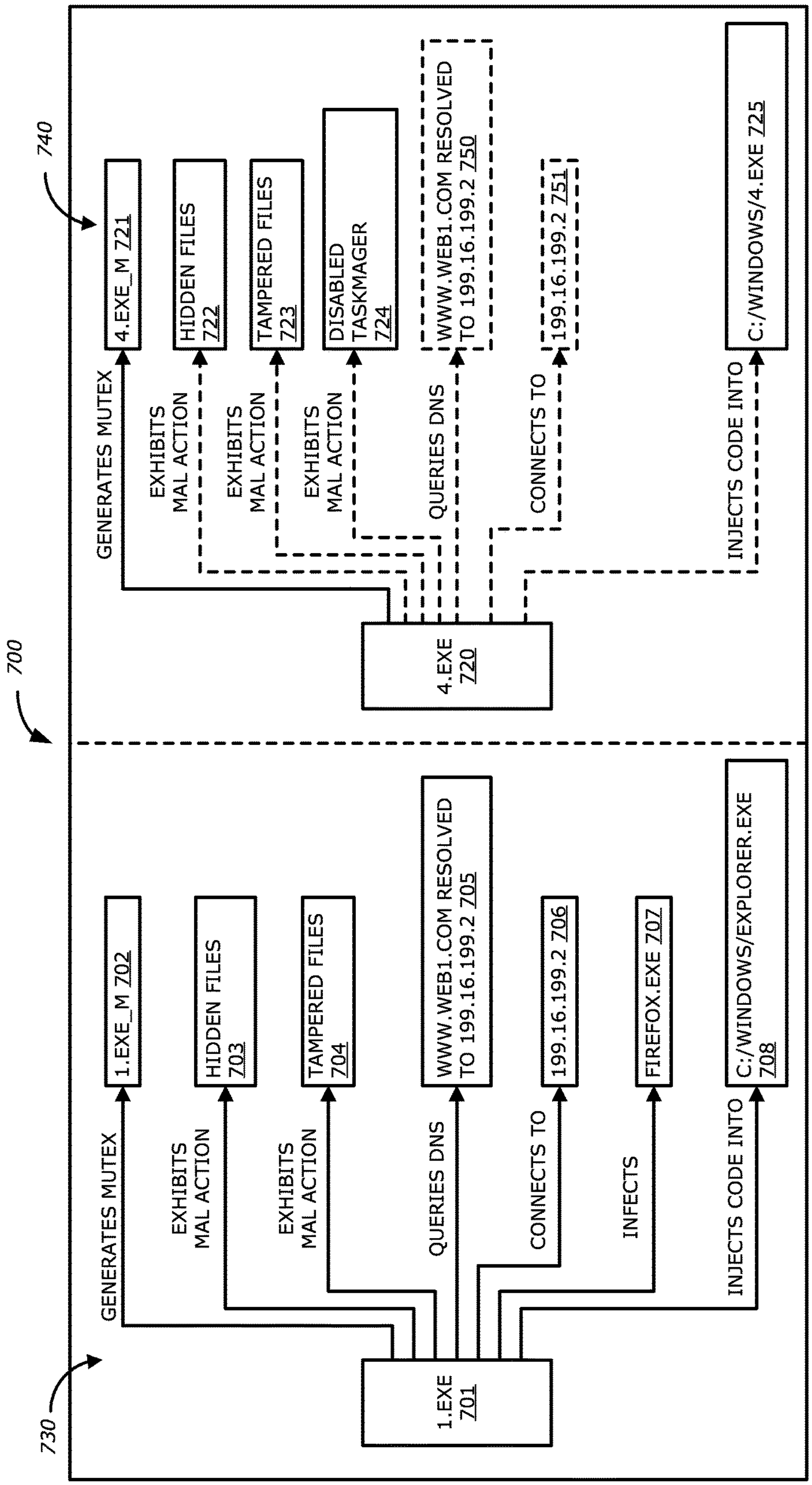

700
730
1.EXE 701
GENERATES MUTEX
1.EXE_M 702
EXHIBITS MAL ACTION
HIDDEN FILES 703
EXHIBITS MAL ACTION
TAMPERED FILES 704
QUERIES DNS
WWW.WEB1.COM RESOLVED TO 199.16.199.2 705
CONNECTS TO
199.16.199.2 706
INFECTS
FIREFOX.EXE 707
INJECTS CODE INTO
C:/WINDOWS/EXPLORER.EXE 708
740
4.EXE 720
GENERATES MUTEX
4.EXE_M 721
EXHIBITS MAL ACTION
HIDDEN FILES 722
EXHIBITS MAL ACTION
TAMPERED FILES 723
EXHIBITS MAL ACTION
DISABLED TASKMAGER 724
QUERIES DNS
WWW.WEB1.COM RESOLVED TO 199.16.199.2 750
CONNECTS TO
199.16.199.2 751
INJECTS CODE INTO
C:/WINDOWS/4.EXE 725

FIG. 7C

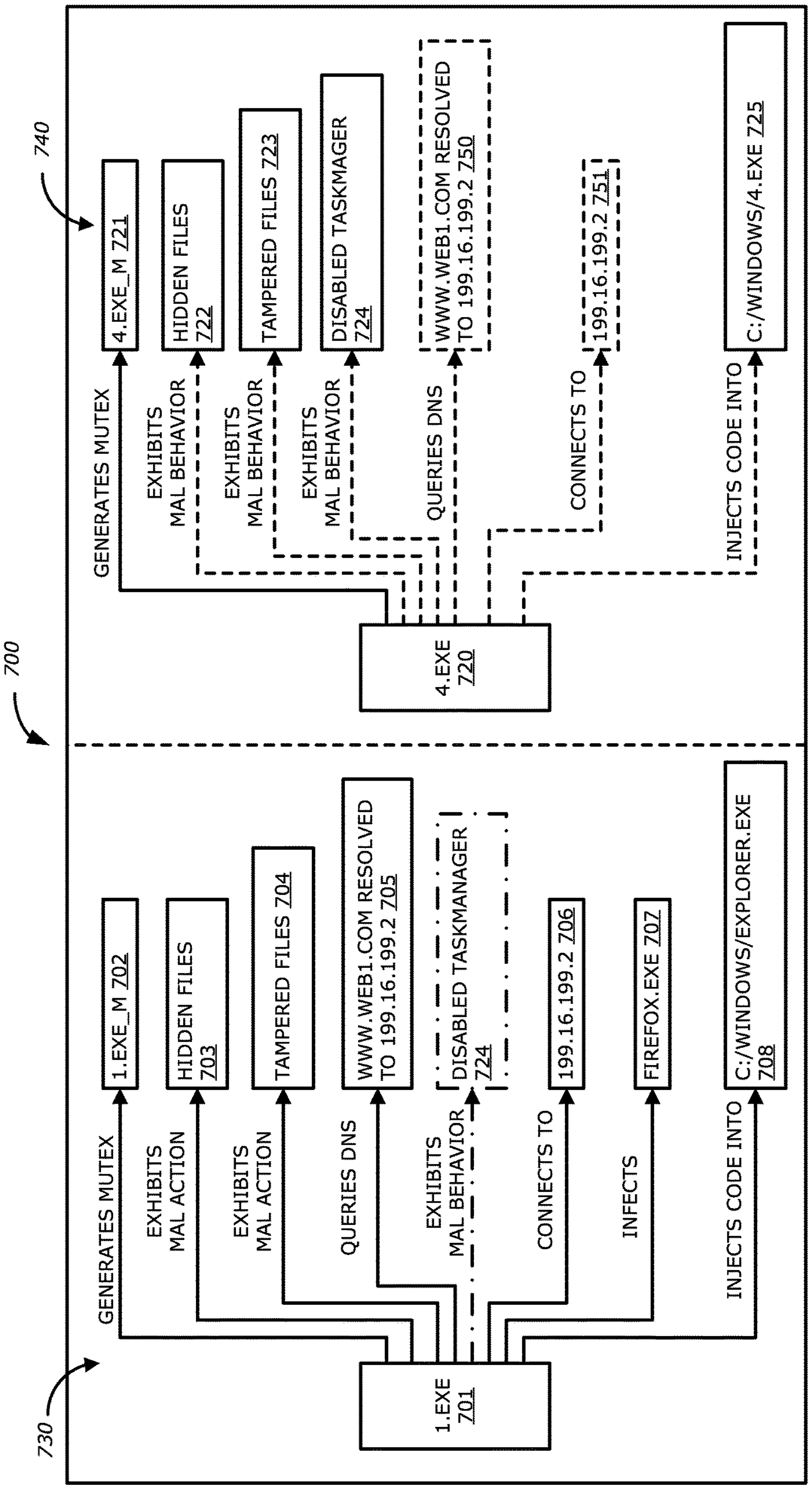

700
730
1.EXE
701
GENERATES MUTEX
1.EXE_M 702
EXHIBITS
MAL ACTION
HIDDEN FILES
703
EXHIBITS
MAL ACTION
TAMPERED FILES 704
QUERIES DNS
WWW.WEB1.COM RESOLVED
TO 199.16.199.2 705
EXHIBITS
MAL BEHAVIOR
DISABLED TASKMANAGER
724
CONNECTS TO
199.16.199.2 706
INFECTS
FIREFOX.EXE 707
INJECTS CODE INTO
C:/WINDOWS/EXPLORER.EXE
708
740
4.EXE
720
GENERATES MUTEX
4.EXE_M 721
EXHIBITS
MAL BEHAVIOR
HIDDEN FILES
722
EXHIBITS
MAL BEHAVIOR
TAMPERED FILES 723
EXHIBITS
MAL BEHAVIOR
DISABLED TASKMAGER
724
QUERIES DNS
WWW.WEB1.COM RESOLVED
TO 199.16.199.2 750
CONNECTS TO
199.16.199.2 751
INJECTS CODE INTO
C:/WINDOWS/4.EXE 725

FIG. 7D

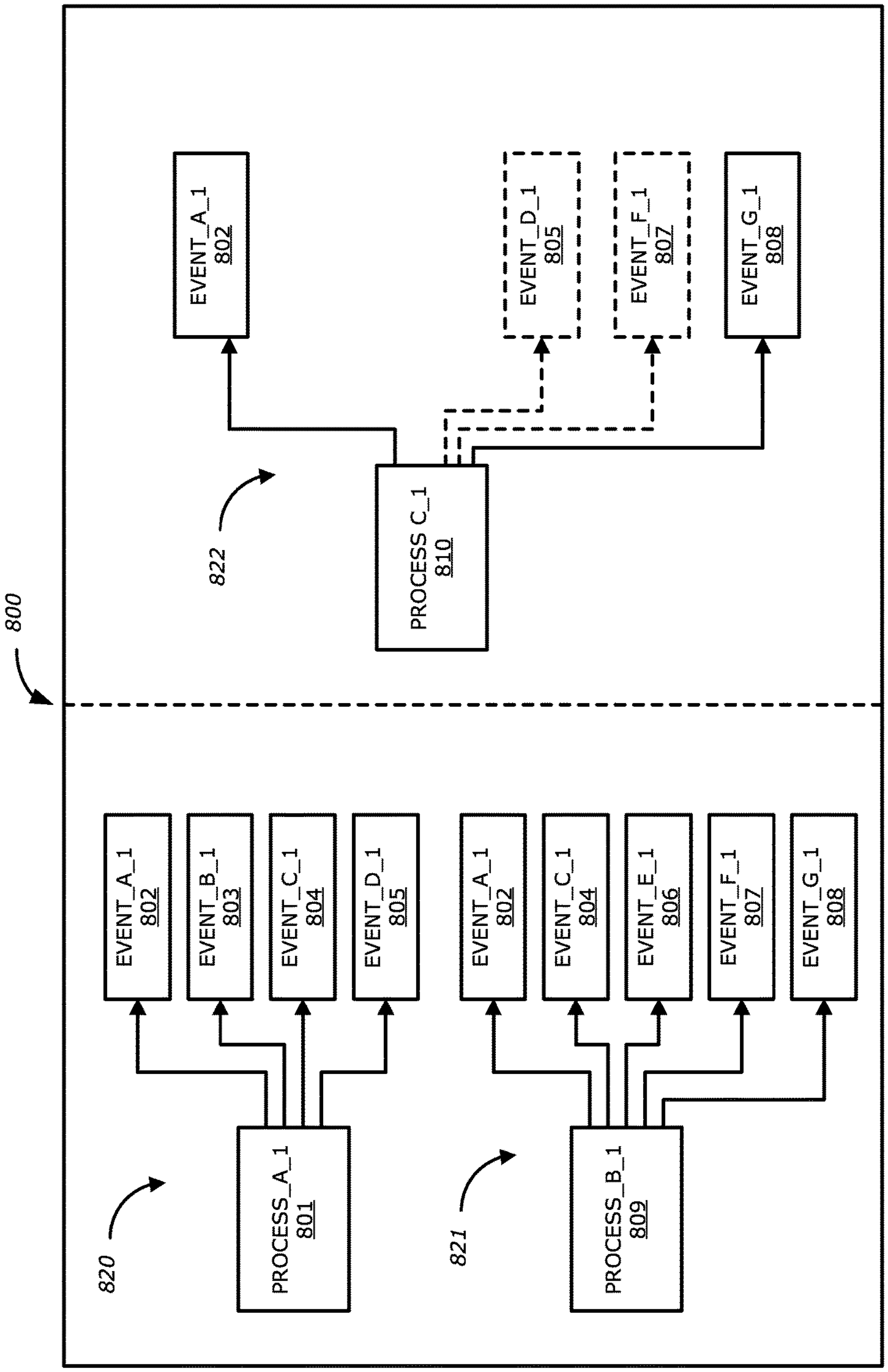

800
820
PROCESS_A_1
801
EVENT_A_1
802
EVENT_B_1
803
EVENT_C_1
804
EVENT_D_1
805
821
PROCESS_B_1
809
EVENT_A_1
802
EVENT_C_1
804
EVENT_E_1
806
EVENT_F_1
807
EVENT_G_1
808
822
PROCESS C_1
810
EVENT_A_1
802
EVENT_D_1
805
EVENT_F_1
807
EVENT_G_1
808

FIG. 8

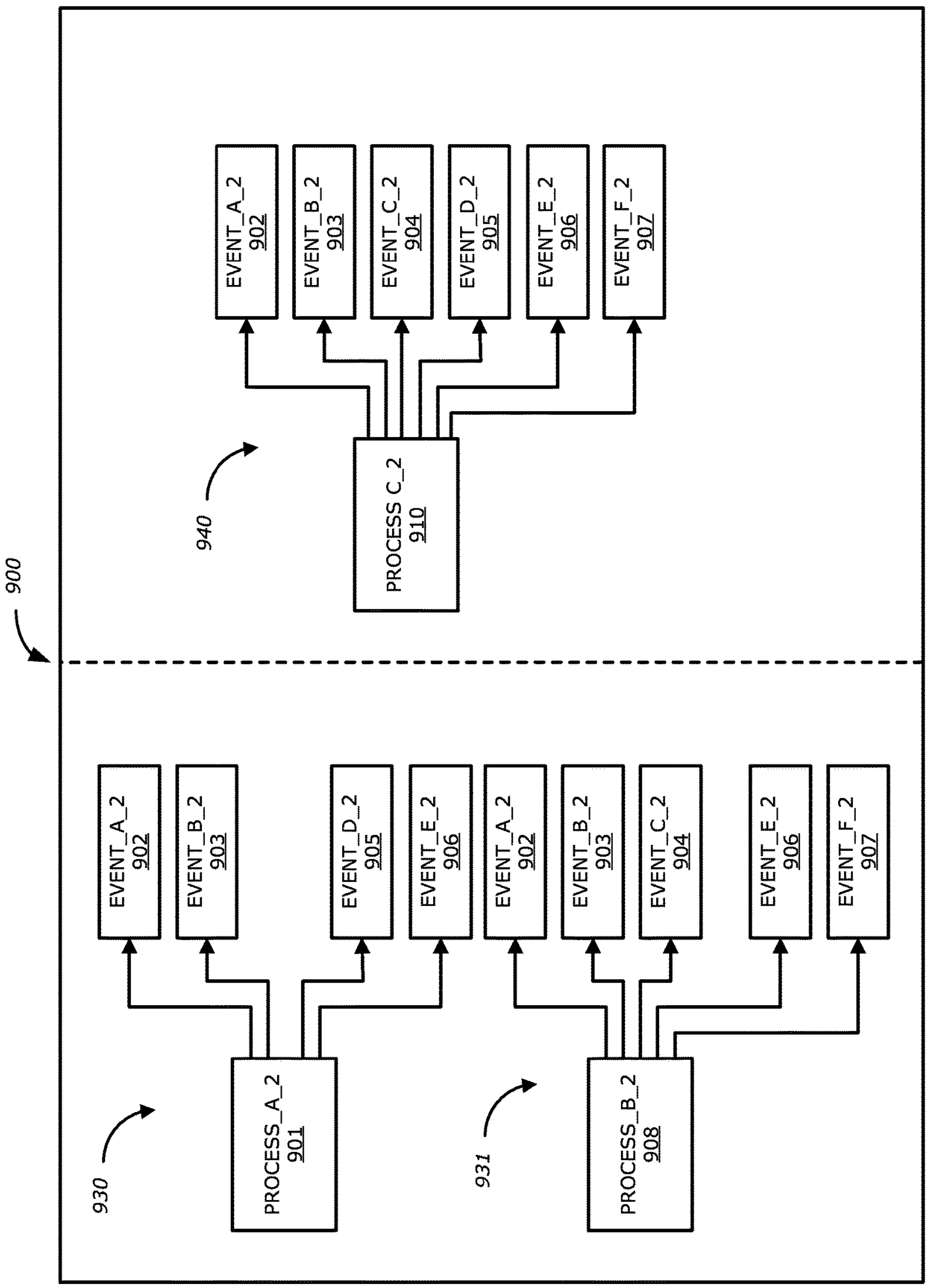
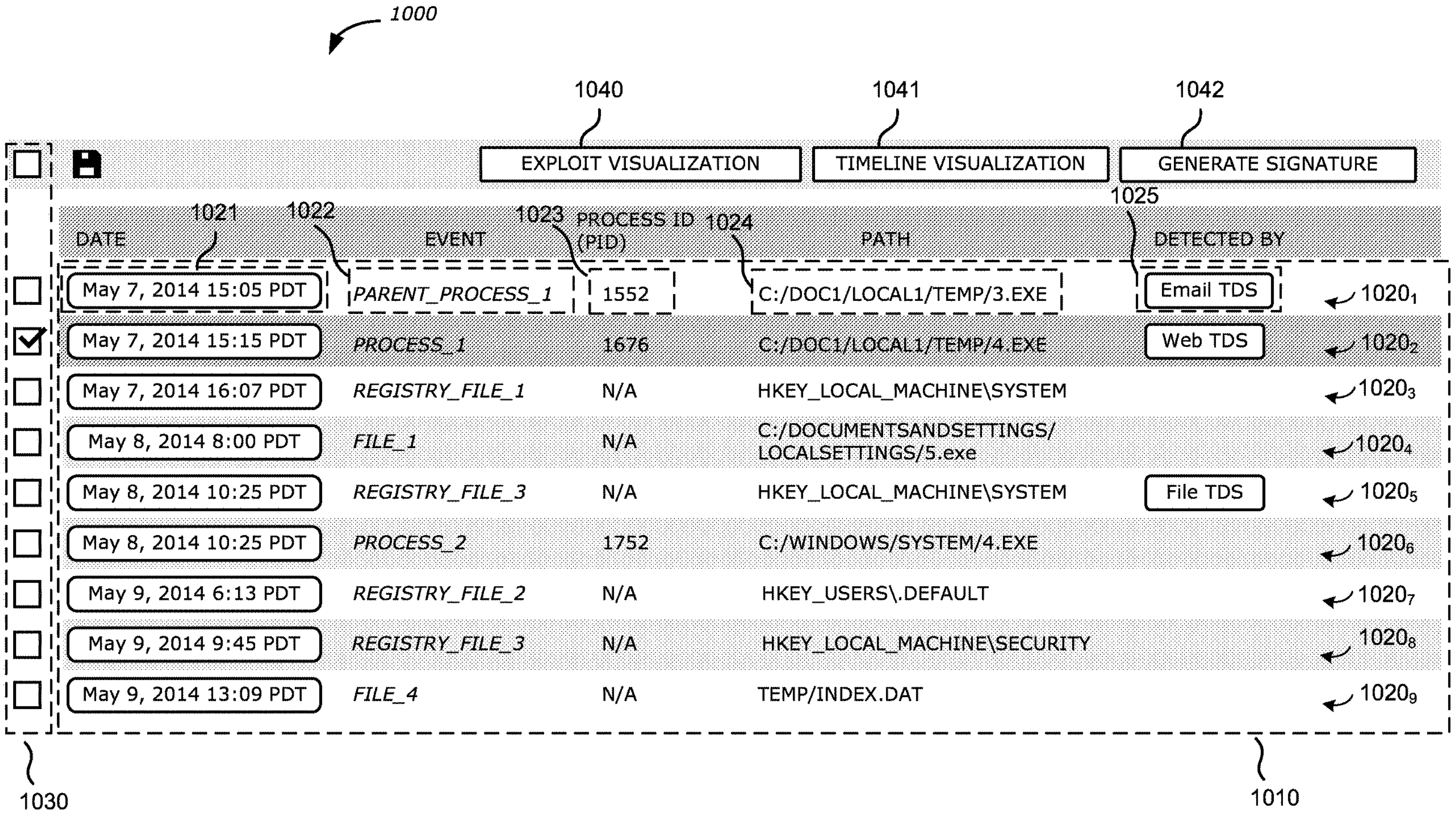
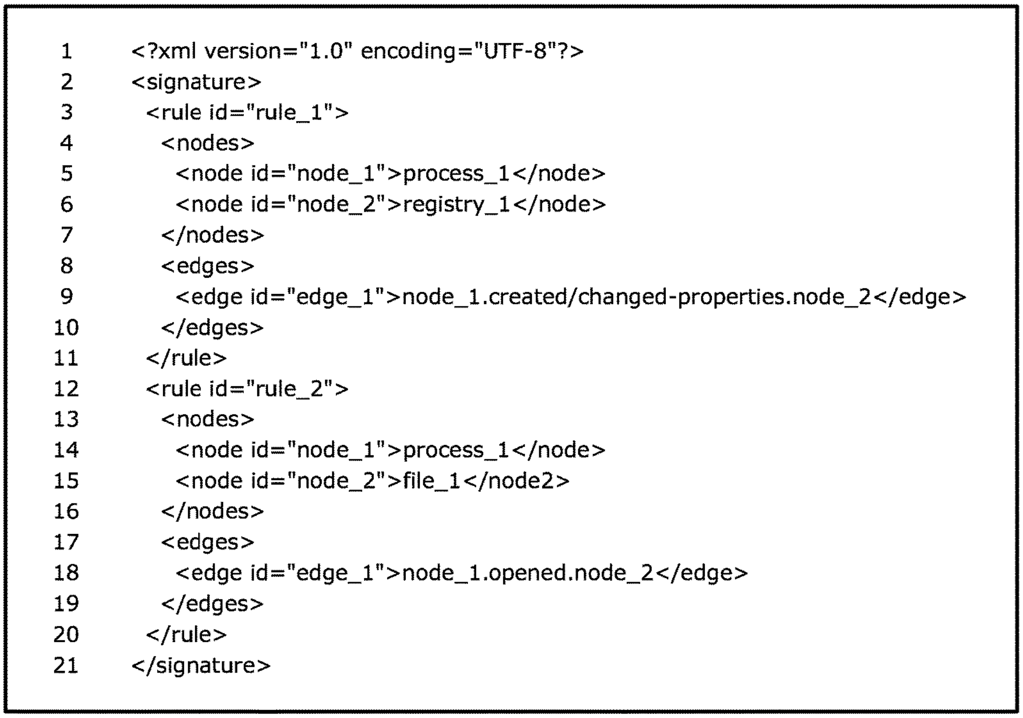

900
930
PROCESS_A_2
901
EVENT_A_2
902
EVENT_B_2
903
EVENT_D_2
905
EVENT_E_2
906
931
PROCESS_B_2
908
EVENT_A_2
902
EVENT_B_2
903
EVENT_C_2
904
EVENT_E_2
906
EVENT_F_2
907
940
PROCESS C_2
910
EVENT_A_2
902
EVENT_B_2
903
EVENT_C_2
904
EVENT_D_2
905
EVENT_E_2
906
EVENT_F_2
907

FIG. 9



	DATE	EVENT	PROCESS ID (PID)	PATH	DETECTED BY
□	May 7, 2014 15:05 PDT	*PARENT_PROCESS_1*	1552	C:/DOC1/LOCAL1/TEMP/3.EXE	Email TDS
☑	May 7, 2014 15:15 PDT	*PROCESS_1*	1676	C:/DOC1/LOCAL1/TEMP/4.EXE	Web TDS
□	May 7, 2014 16:07 PDT	*REGISTRY_FILE_1*	N/A	HKEY_LOCAL_MACHINE\SYSTEM	
□	May 8, 2014 8:00 PDT	*FILE_1*	N/A	C:/DOCUMENTSANDSETTINGS/ LOCALSETTINGS/5.exe	
□	May 8, 2014 10:25 PDT	*REGISTRY_FILE_3*	N/A	HKEY_LOCAL_MACHINE\SYSTEM	File TDS
□	May 8, 2014 10:25 PDT	*PROCESS_2*	1752	C:/WINDOWS/SYSTEM/4.EXE	
□	May 9, 2014 6:13 PDT	*REGISTRY_FILE_2*	N/A	HKEY_USERS\.DEFAULT	
□	May 9, 2014 9:45 PDT	*REGISTRY_FILE_3*	N/A	HKEY_LOCAL_MACHINE\SECURITY	
□	May 9, 2014 13:09 PDT	*FILE_4*	N/A	TEMP/INDEX.DAT	

FIG. 10



```
<?xml version="1.0" encoding="UTF-8"?>
<signature>
  <rule id="rule_1">
    <nodes>
      <node id="node_1">process_1</node>
      <node id="node_2">registry_1</node>
    </nodes>
    <edges>
      <edge id="edge_1">node_1.created/changed-properties.node_2</edge>
    </edges>
  </rule>
  <rule id="rule_2">
    <nodes>
      <node id="node_1">process_1</node>
      <node id="node_2">file_1</node2>
    </nodes>
    <edges>
      <edge id="edge_1">node_1.opened.node_2</edge>
    </edges>
  </rule>
</signature>
```

FIG. 11

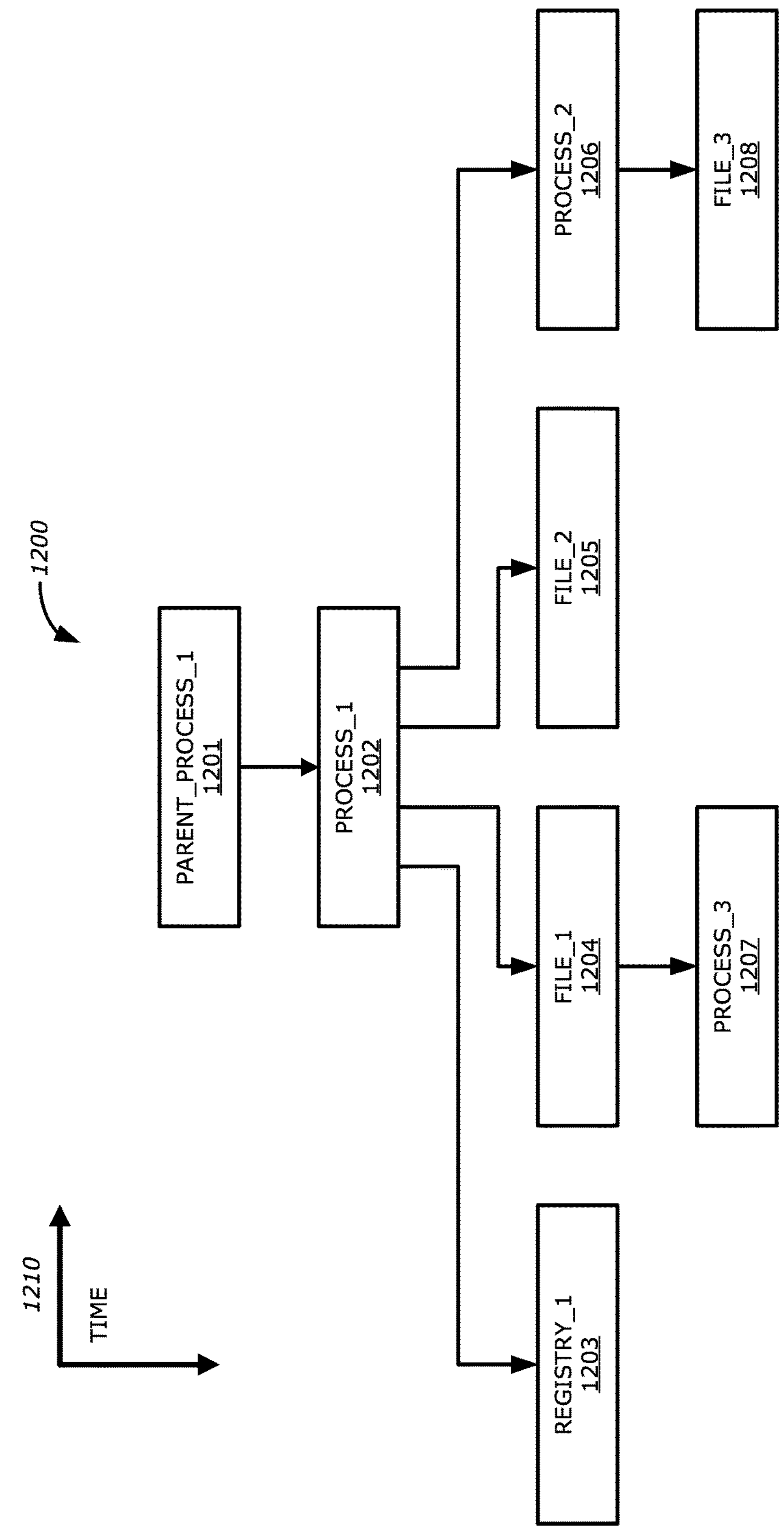

1200
1210
TIME
PARENT_PROCESS_1
1201
PROCESS_1
1202
REGISTRY_1
1203
FILE_1
1204
FILE_2
1205
PROCESS_2
1206
PROCESS_3
1207
FILE_3
1208

FIG. 12

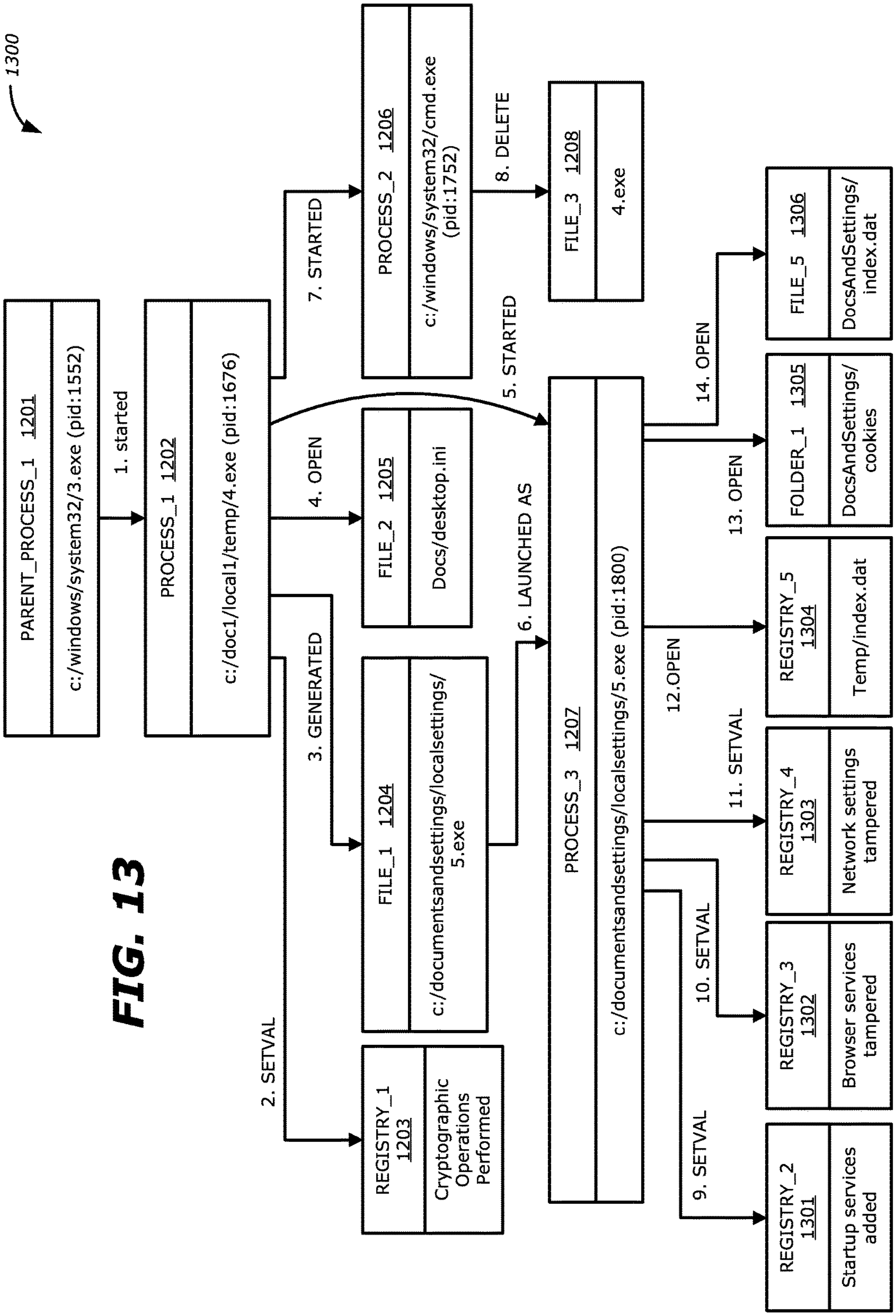

1300
PARENT_PROCESS_1 1201
c:/windows/system32/3.exe (pid:1552)
1. started
PROCESS_1 1202
c:/doc1/local1/temp/4.exe (pid:1676)
2. SETVAL
REGISTRY_1 1203
Cryptographic Operations Performed
3. GENERATED
FILE_1 1204
c:/documentsandsettings/localsettings/5.exe
4. OPEN
FILE_2 1205
Docs/desktop.ini
5. STARTED
6. LAUNCHED AS
7. STARTED
PROCESS_2 1206
c:/windows/system32/cmd.exe (pid:1752)
8. DELETE
FILE_3 1208
4.exe
PROCESS_3 1207
c:/documentsandsettings/localsettings/5.exe (pid:1800)
9. SETVAL
REGISTRY_2 1301
Startup services added
10. SETVAL
REGISTRY_3 1302
Browser services tampered
11. SETVAL
REGISTRY_4 1303
Network settings tampered
12.OPEN
REGISTRY_5 1304
Temp/index.dat
13. OPEN
FOLDER_1 1305
DocsAndSettings/cookies
14. OPEN
FILE_5 1306
DocsAndSettings/index.dat

FIG. 13

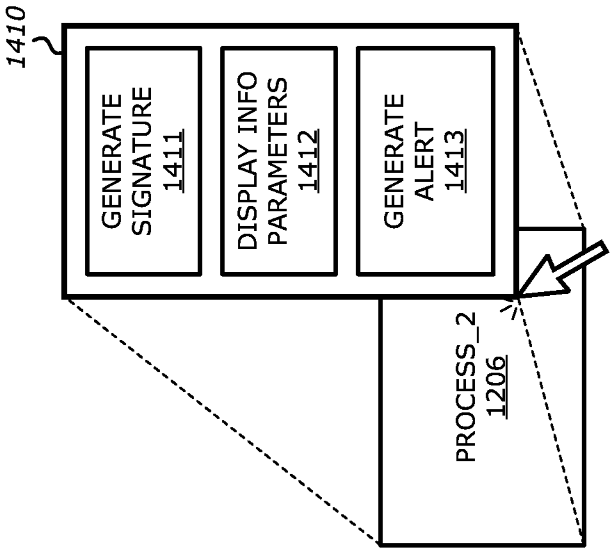
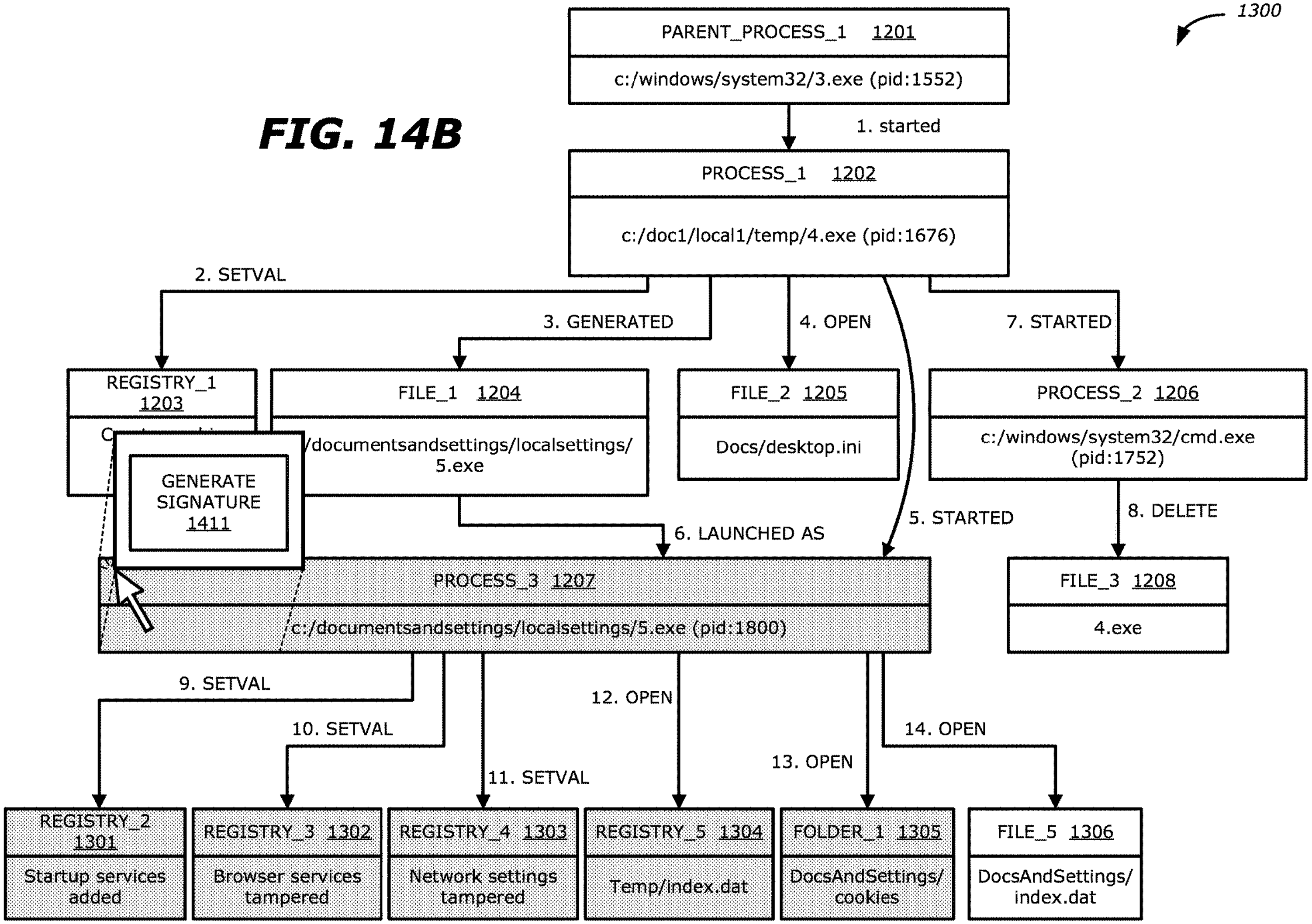
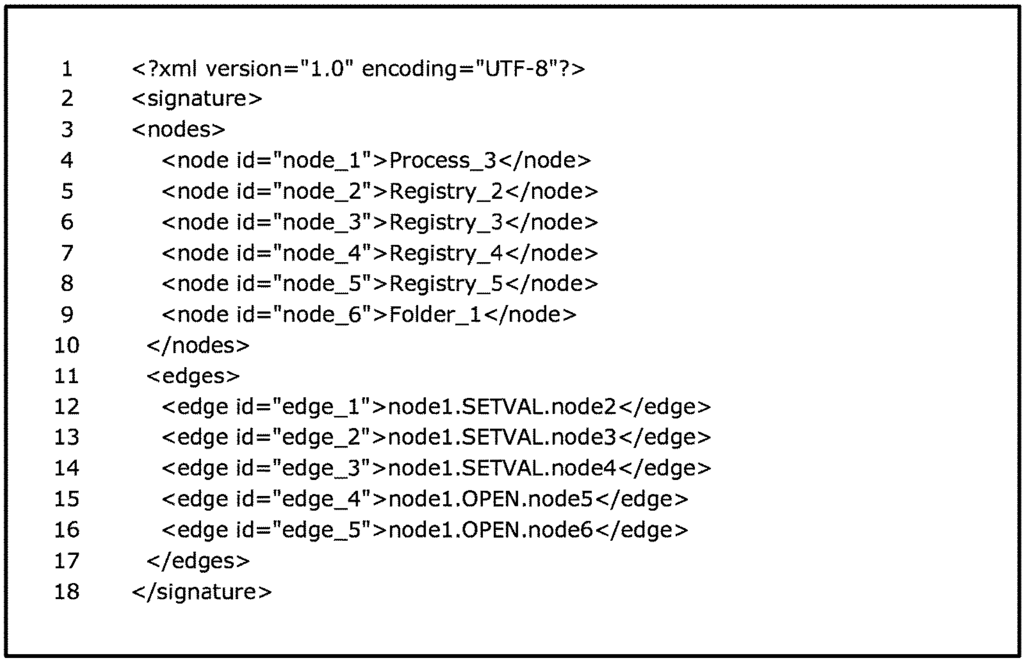

1410
GENERATE SIGNATURE 1411
DISPLAY INFO PARAMETERS 1412
GENERATE ALERT 1413
PROCESS_2 1206

FIG. 14A

FIG. 14B


1300
PARENT_PROCESS_1 1201
c:/windows/system32/3.exe (pid:1552)
1. started
PROCESS_1 1202
c:/doc1/local1/temp/4.exe (pid:1676)
2. SETVAL
3. GENERATED
4. OPEN
7. STARTED
REGISTRY_1 1203
FILE_1 1204
/documentsandsettings/localsettings/ 5.exe
FILE_2 1205
Docs/desktop.ini
PROCESS_2 1206
c:/windows/system32/cmd.exe (pid:1752)
GENERATE SIGNATURE 1411
6. LAUNCHED AS
5. STARTED
8. DELETE
PROCESS_3 1207
c:/documentsandsettings/localsettings/5.exe (pid:1800)
FILE_3 1208
4.exe
9. SETVAL
10. SETVAL
11. SETVAL
12. OPEN
13. OPEN
14. OPEN
REGISTRY_2 1301
Startup services added
REGISTRY_3 1302
Browser services tampered
REGISTRY_4 1303
Network settings tampered
REGISTRY_5 1304
Temp/index.dat
FOLDER_1 1305
DocsAndSettings/ cookies
FILE_5 1306
DocsAndSettings/ index.dat



```xml
<?xml version="1.0" encoding="UTF-8"?>
<signature>
<nodes>
    <node id="node_1">Process_3</node>
    <node id="node_2">Registry_2</node>
    <node id="node_3">Registry_3</node>
    <node id="node_4">Registry_4</node>
    <node id="node_5">Registry_5</node>
    <node id="node_6">Folder_1</node>
  </nodes>
  <edges>
    <edge id="edge_1">node1.SETVAL.node2</edge>
    <edge id="edge_2">node1.SETVAL.node3</edge>
    <edge id="edge_3">node1.SETVAL.node4</edge>
    <edge id="edge_4">node1.OPEN.node5</edge>
    <edge id="edge_5">node1.OPEN.node6</edge>
  </edges>
</signature>
```

FIG. 15

INTERACTIVE INFECTION VISUALIZATION FOR IMPROVED EXPLOIT DETECTION AND SIGNATURE GENERATION FOR MALWARE AND MALWARE FAMILIES

FIELD

Embodiments of the disclosure relate to the field of cyber security. More specifically, embodiments of the disclosure relate to a system for generating reference models to describe known instances of anomalous, or more specifically, malicious behavior and interactive display screens to illustrate a comparison between incoming data and one or more reference models.

GENERAL BACKGROUND

Over the last decade, malicious software has become a pervasive problem for Internet users as many networked resources include vulnerabilities that are subject to attack. For instance, over the past few years, more and more vulnerabilities are being discovered in software that is loaded onto endpoint devices present on the network, such as vulnerabilities within operating systems for example. These vulnerabilities may be exploited by a person allowing the person to gain access to one or more areas within the network not typically accessible. For example, a person may exploit a vulnerability to gain unauthorized access to email accounts and/or data files.

While some vulnerabilities continue to be addressed through software patches, prior to the release of such software patches, network devices will continue to be targeted for attack by exploits, namely malicious computer code that attempts to acquire sensitive information or adversely influence or attack normal operations of the network device or the entire enterprise network by taking advantage of a vulnerability in computer software.

Currently, a threat detection system observes suspicious or malicious exploits and presents the information regarding the exploits in a list format. While the list format may provide security personnel information directed to uncovered exploits or other detected malicious actions, it fails to identify any relationships between the exploits that would allow security personnel to better understand potential effects, both detected and undetected, caused by the malicious exploit.

In addition, current systems fail to generate reference models based on observed exploits, malicious behaviors, anomalous behaviors (e.g., deviating from typical or expected behavior) or the like for comparison against events observed at a later time.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

FIG. **1** a flowchart illustrating an exemplary method for generating a reference model and the applications that may be performed by a malware detection and visualization system (MDVS) using the generated reference model.

FIG. **2** is a block diagram of an exemplary malware detection and visualization system (MDVS) **200** coupled to a network **240**.

FIG. **3** is an exemplary embodiment of a logical representation of the MDVS of FIG. **2**.

FIG. **4** is an exemplary portion of data received by the event log engine **230** expressed in eXtensible Markup Language (XML).

FIG. **5** is an exemplary portion of data generated by either the reference model generating logic **215** or the machine learning logic **211** expressed in XML.

FIG. **6** is an exemplary illustration of a comparison of a reference model of an association of known malicious events with an association of potentially malicious observed events.

FIGS. **7**A-**7**D are exemplary diagrams illustrating the exploit detection process performed by the matching logic **213** comparing an association of potentially malicious observed events with a reference model of known malicious events.

FIG. **8** is an exemplary illustration of a comparison **800** of reference models **820** and **821** with an association of potentially malicious observed events.

FIG. **9** is an exemplary illustration of a process of generating a malware family reference model.

FIG. **10** is an exemplary embodiment of an interactive display screen for display of associated events and/or particulars of the associated events used in generating the interactive display screens of FIGS. **12**-**14**B.

FIG. **11** is an exemplary portion of data generated by either the reference model generating logic **215** or the machine learning logic **211** expressed in XML.

FIG. **12** is an exemplary illustration of a first embodiment of an interactive display screen for display of associated events and particulars of the associated events.

FIG. **13** is an exemplary illustration of a detailed embodiment of the interactive display screen of FIG. **12**.

FIG. **14**A is an exemplary illustration of a portion of an interactive display screen for enabling a viewer to generate a signature of a selected event, display particulars of the selected event and/or generate an alert for a selected event.

FIG. **14**B is an exemplary illustration of a second embodiment of an interactive display screen for enabling a viewer to generate a signature of a selected event.

FIG. **15** is an exemplary portion of the generated signature (corresponding to the selected section in FIG. **14**B) expressed in XML.

DETAILED DESCRIPTION

Various embodiments of the disclosure relate to a malware detection and visualization system that improves exploit detection and/or visual representation of the detection of suspected malware. The malware detection and visualization system includes a machine learning engine that generates reference models used in exploit detection as well as interactive display screen information based on data transmitted to the malware detection and visualization system from one or more endpoint devices, one or more threat detection systems and/or cloud computing services. The generated reference models may be combined to generate malware family reference models allowing the malware detection and visualization system to compare observed events on the network to particularized malware threats in the form of malware affecting a specific file type or malware detected in a common location (e.g., email). Alternatively, a comparison with several reference models or with a large malware family reference model may provide detection against a large range of malware threats. The malware detection and visualization system may take the form of a security appliance or security cloud service, for example. Alternatively, an electronic device may be configured with software, hardware or firmware that includes a malware detection and visualization system. The malware detection and visualization system may be implemented in real-time (e.g., as incoming data is being processed) or as a forensic investigative tool (e.g., after the incoming data has been processed to determine the root cause of a malware exploited has been executed).

The malware detection and visualization system also includes a user interface rendering subsystem that generates interactive display screens from the interactive display screen information and allows security personnel to select displayed malicious events in order to acquire additional information concerning such events as well as generate an alert or a (malware) signature that may be used for subsequent detection of malware associated with these malicious events. The interactive display screens provide a network administrator with a visual representation that compares a reference model of events (e.g., known exploits) and the relationships connecting the events with a group of potentially malicious events and their relationships to one another. The group of potentially malicious events may be derived from observations of endpoint devices, threat detection systems and/or cloud computing services connected to the malware detection and visualization system over a network.

Specifically, in one embodiment, the visual representation allows a viewer to convert a list of events into a nodal diagram in either a top-down representation or a left-to-right representation. The nodal diagrams may enable a view, such as network security personnel, to see how each event relates to one another, if at all. Furthermore, the nodal diagrams provide the visual representation necessary for a viewer to select one or more events, referred to herein as a "grouping" of events, to generate a signature or alert. The signature of a grouping of events may be used as a reference model to check for a particular sequence of events in data received in the future or added to an existing reference model. The alert may be used to notify the network administrator of the observation of a grouping of events that typically implies malicious activity on the network thereby allowing prevention actions to be taken to guard against the malicious activity.

Embodiments of the invention may be employed by or take the form of a network device or apparatus implementing a malware detection and visualization system (MDVS), where the malware detection and visualization system includes a machine learning engine for analyzing data received by the MDVS. The data may include information regarding the observation of events by a server or client device or other system (called an "endpoint"), a threat detection systems (TDS) and/or a cloud computing service. In some embodiments, the observations of events may take place while an endpoint device is operating in real-time or the observations may take place while incoming data is being processed in one or more virtual machines. Examples of incoming data may include, but are not limited or restricted to, network traffic, static files containing structured or unstructured data maintained locally or on a peripheral device and/or executable files. According to one embodiment of the disclosure, an endpoint device, TDS or cloud computing service transmits data regarding an observation of one or more events and/or relationships when an anomalous characteristic of incoming data is observed and thus indicative of an exploit. If so, one or more portions of data may be labeled "suspicious." Throughout the specification, claims and figures, the term "network traffic" will be used in the discussion but any form of incoming data may be substituted.

A TDS may perform static and/or dynamic analyses on incoming data (e.g., network traffic) to determine whether an object of the incoming data is suspicious or malicious. An illustrative example of the static and dynamic analyses is illustrated in the threat detection and prevention (TDP) system in a prior U.S. Patent Application entitled "System, Apparatus and Method for Automatically Verifying Exploits Within Suspect Objects and Highlighting the Display Information Associated with the Verified Exploits," U.S. patent application Ser. No. 14/228,073 filed Mar. 27, 2014, the contents of which are incorporated by reference.

In particular, the machine learning engine may be activated automatically in response to an alert condition that signifies detection of a malicious event by an endpoint device, a TDS and/or a cloud computing service within the network. Alternatively, the machine learning engine may be activated in accordance with a time-based schedule or manually by a user such as security personnel. For instance, the machine learning engine may be activated manually upon selecting a particular visual representation associated with the observance of a malicious event, where one or more events may be concurrently presented on an interactive display screen, and then subsequently selecting a prescribed item on the display screen (e.g., "exploit visualization" button or "timeline visualization" button).

After activation, the machine learning engine may be adapted to obtain received data from a machine learning data store and/or event log, where the received data may include metadata associated with malicious events detected by one or more endpoint devices, TDSes and/or a cloud computing service. The machine learning engine generates a visual representation in the form of a nodal diagram illustrating a potential malware infection, where each node or relationship included in the nodal diagram represents an action, operation, file, process, etc. associated with an anomalous event or relationship. This provides a network administrator with one or more displays directed to the sequence of events to identify which network device(s) and or file(s) within the network may have been infected by the anomalous event. For example, the anomalous event may be an atypical, but non-malicious, operation or relationship; alternatively, the anomalous event may be realized as a malicious event or relationship.

In the nodal diagrams, each event may be selected to display additional information, including, any or all of the following metadata directed to the observance of the selected event: (1) time and date of observance; (2) address information such as the path within the file system in which the affected file is located; (3) process identification of the affected process (if applicable); (4) the particulars of the particular electronic device or cloud computing service that detected the event; and/or (5) the relationship to one or more events associated with the selected event.

I. Terminology

In the following description, certain terminology is used to describe features of the invention. For example, in certain situations, both terms "logic" and "engine" are representative of hardware, firmware and/or software that is configured to perform one or more functions. As hardware, logic (or engine) may include circuitry having data processing or storage functionality. Examples of such circuitry may include, but are not limited or restricted to a microprocessor, one or more processor cores, a programmable gate array, a microcontroller, a controller, an application specific integrated circuit, wireless receiver, transmitter and/or transceiver circuitry, semiconductor memory, or combinatorial logic.

Logic (or engine) may be software in the form of one or more software modules, such as executable code in the form of an executable application, an application programming interface (API), a subroutine, a function, a procedure, an applet, a servlet, a routine, source code, object code, a shared library/dynamic load library, or one or more instructions. These software modules may be stored in any type of a suitable non-transitory storage medium, or transitory storage medium (e.g., electrical, optical, acoustical or other form of propagated signals such as carrier waves, infrared signals, or digital signals). Examples of non-transitory storage medium may include, but are not limited or restricted to a programmable circuit; a semiconductor memory; non-persistent storage such as volatile memory (e.g., any type of random access memory "RAM"); persistent storage such as non-volatile memory (e.g., read-only memory "ROM", power-backed RAM, flash memory, phase-change memory, etc.), a solid-state drive, hard disk drive, an optical disc drive, or a portable memory device. As firmware, the executable code is stored in persistent storage.

An "exploit" may be construed broadly as information (e.g., executable code, data, command(s), etc.) that attempts to take advantage of a vulnerability and/or an action by a person gaining unauthorized access to one or more areas of a network, a computer and/or an electronic device. Typically, a "vulnerability" is a coding error or artifact of software (e.g., computer program) that allows an attacker to alter legitimate control flow during processing of the software (computer program) by a network device, and thus, causes the network device to experience undesirable or anomalous behaviors. The undesired or anomalous behaviors may include a communication-based anomaly or an execution-based anomaly, which, for example, could (1) alter the functionality of an network device executing application software in an atypical manner (a file is opened by a first process where the file is configured to be opened by a second process and not the first process); (2) alter the functionality of the network device executing that application software without any malicious intent; and/or (3) provide unwanted functionality which may be generally acceptable in another context. To illustrate, a computer program may be considered as a state machine, where all valid states (and transitions between states) are managed and defined by the program, in which case an exploit may be viewed as seeking to alter one or more of the states (or transitions) from those defined by the program. The term "anomalous behavior" should be understood to include either (i) a first event that is an atypical occurrence or a malicious occurrence, or (ii) a relationship identifying that the first event is based on a second event, the relationship being an atypical relationship between the first and second event or a relationship between the first and second events that is malicious to the network, electronic device on which the relationship appears, or to one or more users of the electronic device or of the network.

According to one embodiment, malware may be construed broadly as computer code that executes an exploit to take advantage of a vulnerability, for example, to harm or co-opt operation of a network device or misappropriate, modify or delete data. Conventionally, malware is often said to be designed with malicious intent.

The term "transmission medium" is a physical or logical communication path between two or more network devices (e.g., any devices with data processing and network connectivity such as, for example, a security appliance, a server, a mainframe, a computer such as a desktop or laptop, netbook, tablet, firewall, smart phone, router, switch, bridge, etc.). For instance, the communication path may include wired and/or wireless segments. Examples of wired and/or wireless segments include electrical wiring, optical fiber, cable, bus trace, or a wireless channel using infrared, radio frequency (RF), or any other wired/wireless signaling mechanism.

The term "network device" should be construed as any electronic device with the capability of connecting to a network. Such a network may be a public network such as the Internet or a private network such as a wireless data telecommunication network, wide area network, a type of local area network (LAN), or a combination of networks. Examples of a network device may include, but are not limited or restricted to, a laptop, a mobile phone, a tablet, a computer, etc.

The term "computerized" generally represents that any corresponding operations are conducted by hardware in combination with software and/or firmware. Also, the terms "compare" or "comparison" generally mean determining if a match (e.g., a certain level of correlation) is achieved between two items where one of the items may include a particular signature pattern.

The term "signature" designates an indicator of a set of characteristics and/or behaviors exhibited by one or more exploits that may not be unique to those exploit(s). Thus, a match of the signature may indicate to some level of probability, often well less than 100%, that a portion of received data constitutes an exploit. In some contexts, those of skill in the art have used the term "signature" as a unique identifier or "fingerprint," for example of a specific virus or virus family (or other exploit), which is generated for instance as a hash of its machine code, and that is a special sub-case for purposes of this disclosure.

The term "observed" indicates that an event or relationship has been detected with a prescribed level of confidence (or probability). A first event or relationship may be observed with a first confidence while a second event or relationship may be observed with a second confidence, the second confidence being lower or higher than the first confidence. Examples of an event may include, but are not limited or restricted to, a process (e.g., an executable file), a non-executable file (e.g., a text document or a registry file), a unique address or location (e.g., a particular website, Internet Protocol (IP) address, or file location).

The term "reference model" should be interpreted as an association of a plurality of events wherein each event is connected to another event and the association includes at least one anomalous behavior (e.g., anomalous event or relationship). For example, a reference model may include a process that (1) injects code into a file unexpectedly and (2) opens multiple files wherein the opening of the files constitutes anomalous behavior. Throughout the specification and claims, the terms "reference model" and "signature" will be used interchangeably.

The term "relationship" means the connection or association of a first event with a second event. Examples of a relationship may include, but are not limited or restricted to, an event: starting a process, terminating a process, modifying a file, generating a file, opening a file, closing a file, deleting a file, infecting a file and/or process, injecting code into file and/or process and/or generating a mutual exclusion (mutex) on a particular file, process, application, etc.

The term "particular" should be interpreted as a characteristic of an event. Examples of particulars include, but are not limited or restricted to, a process identification (PID), a process name, a file name, a process or file path (i.e., unique location on an electronic device), the date and/or time the event was observed and/or occurred, an application programming interface (API) call involved and/or a hash value of the one or more processes or files involved.

Lastly, the terms "or" and "and/or" as used herein are to be interpreted as inclusive or meaning any one or any combination. Therefore, "A, B or C" or "A, B and/or C" mean "any of the following: A; B; C; A and B; A and C; B and C; A, B and C." An exception to this definition will occur only when a combination of elements, functions, steps or acts are in some way inherently mutually exclusive.

The invention may be utilized for displaying an interactive infection visualization detailing detection, verification and/or prioritization of malicious content. As this invention is susceptible to embodiments of many different forms, it is intended that the present disclosure is to be considered as an example of the principles of the invention and not intended to limit the invention to the specific embodiments shown and described.

II. Malware Detection and Visualization System

Referring to FIG. **1**, a flowchart illustrating an exemplary method for generating a reference model and the applications that may be performed by a network device such as, for example, a malware detection and visualization system (MDVS), using the generated reference model is shown. In block **110**, the MDVS receives data describing observed events from one or more sources connected to a network. The sources may include one or more endpoint devices, one or more threat detection systems (TDSes) and/or cloud computing services. The received data may provide one or more particulars of the observed events and/or describe relationships between the observed events.

At block **120**, the MDVS generates a reference model based on, at least, the received data. The MDVS may use the generated reference to: (i) perform an exploit detection process by comparing data received from one or more sources at a later time to the generated reference model and provide exploit detection feedback to block **120**, if applicable (block **130**); (ii) generate a malware family reference model from a plurality of generated reference models or reference models received over the network (block **140**); and/or (iii) generate one or more interactive display screens to aid in the detection and tracing of exploits and/or one or more anomalous behaviors and provide interactive display screen input to block **120**, if applicable (block **150**).

Referring to FIG. **2**, a block diagram of an exemplary MDVS **200** coupled to a network **240** is shown. The network **240** provides communication connectivity between the MDVS **200** and one or more sources, wherein the sources may include one or more endpoint devices **250**$_1$-**250**$_N$ (where N=2 for this embodiment), one or more threat detection systems (TDSes) **260**$_1$-**260**$_M$ (where M=3 for this embodiment) and/or the cloud computing services **241**. The sources are communicatively coupled to a management system **242**, which is adapted to manage the one or more sources as well as the MDVS **200**. For instance, the management system **242** may be configured to perform content updates (e.g., upload new rules or modified rules, delete rules, modify parameters that are utilized by the rules, upload metadata stored within other TDSes, or certain metadata associated with the one or more endpoint devices **250**$_1$ and/or **250**$_2$) within the one or more endpoint devices **150**$_1$ and **150**$_2$ and/or within the one or more TDSes **260**$_1$-**260**$_3$.

As shown in FIG. **2**, the MDVS **200** is an electronic device that is adapted to analyze information associated with a plurality of events observed at one or more sources (the endpoint devices **250**$_1$ and **250**$_2$, the TDSes **260**$_1$-**260**$_3$ and/or the cloud computing services **241**). The MDVS **200** receives data of the observed events and the particulars of the events over the network **240**. The network **240** may include a public network such as the Internet, a private network such as a wireless data telecommunication network, wide area network, a type of local area network (LAN), or a combination of networks.

In general, the endpoint devices **250**$_1$ and **250**$_2$ may observe one or more events during operation of the device and transmit a log of the events along with particulars of the events to the MDVS **200**. In addition, the TDSes **260**$_1$-**260**$_3$ may observe one or more events while processing, for instance in one or more virtual machines, one or more portions of data received over the network **240**. The TDSes **260**$_1$-**260**$_3$ may then transmit a log containing the events and their particulars to the MDVS **200**. The management system **242** controls the transmission of the event logs by the endpoint devices **250**$_1$ and **250**$_2$ and/or the TDSes **260**$_1$-**260**$_3$. For example, the management system **242** may transmit notifications to the endpoint devices **250**$_1$ and **250**$_2$ and/or the TDSes **260**$_1$-**260**$_3$ instructing the sources that the event logs should be transmitted to the MDVS **200**.

As illustrated in FIG. **2**, the MDVS **200** includes a machine learning engine **210**, a user interface (UI) rendering subsystem **220** and an event log engine **230**. Herein, the machine learning engine **210** may include a machine learning logic **211**, a machine learning data store **214**, a gathering logic **212**, a matching logic **213**, and a reference model generation logic **215**. The UI rendering subsystem **220** may include a display generation logic **221** and a UI logic **222**. The event log engine may include an event log control logic **231** and an event log **232**.

In one embodiment, the event log control logic **231** is responsible for receiving data associated with a malicious event that may be detected at and transmitted by the one or more sources over the network **240**. Upon receiving the data, the event log control logic **231** may categorize the event and any associated events included in the data, for example, according to the type of event (e.g., executable file, text file, registry file, etc.). The data associated with a malicious event includes the particulars of the malicious event and the particulars of any observed events associated with the malicious event. The event log control logic **231** further adds the particulars of each observed event to the event log **232**. Therefore, the MDVS **200** is able to easily access the event particulars in a sorted manner when generating an interactive display screen.

In a second embodiment wherein the MDVS **200** is deployed within an endpoint device **250**$_1$, the event log control logic **231** is also responsible for observing the events at the endpoint device on which the MDVS **200** is deployed and for adding data associated with an observed malicious event to the event log **232** as well.

The machine learning logic **211** is responsible for analyzing the data associated with the observed events. The gathering logic **212** of the machine learning logic **211** may query the event log **232** to obtain the one or more portions of the data. The matching logic **213** of the machine learning logic **211** may analyze the one or more portions of the data to generate associations of one or more events based on the particulars of the events. For instance, the machine learning logic **211** may realize a first process (e.g., a parent process) launched several secondary processes (e.g., child processes) and that the child processes subsequently modified one or more files. In addition, the machine learning logic **211** may perform a comparison between the above-referenced realization and one or more reference models formed by events and relationships where one of these events or relationships may be characterized as a known anomalous behavior. Furthermore, the reference model generation logic **215** of the machine learning logic **211** may generate reference models of malware families from the data stored in the event log **232** and data stored in the machine learning data store **214** (the generation of reference models of malware families will be described in detail below). The machine learning logic **211** also generates the interactive display screen information based on the data in the machine learning data store **214** and the event log **232**. In one embodiment, the generated reference models of malware families and the interactive display screen information may be expressed in eXtensible Markup Language (XML) and stored in the machine learning data store **214** (as will be discussed below with FIGS. **4** and **5**).

The machine learning data store **214** stores the reference models generated by the machine learning logic **211** or received over the network **240** if applicable. For example, an MDVS may be deployed within an endpoint device **250**$_1$ and/or **250**$_2$, within one or more TDSes **260**$_1$-**260**$_3$, or within the cloud computing services **241**. In that such an embodiment, the MDVS **200** may receive one or more reference models generated by the MDVS deployed within the endpoint device **250**$_1$. The machine learning data store **214** also stores interactive display screens generated by the machine learning logic **211**. In the embodiment wherein an MDVS is deployed within the endpoint device **250**$_1$, the data received over the network may include previously generated reference models and/or interactive display screen information. The MDVS **200** may adopt such data without modification or analyze such data to generate its own reference models and/or interactive display screen data in combination with previously received data.

The display generation logic **221** is responsible for displaying the interactive display screens generated from the interactive display screen information generated by the machine learning logic **211**. When a request to display an interactive display screen is received by the MDVS **200**, the user interface logic **222** notifies the machine learning logic **211**. The machine learning logic **211** then queries the machine learning data store **214** and the event log **232** for the appropriate data (e.g., data pertaining to the relevant event (s)) and generates the interactive display screen information. The machine learning logic **211** may transmit the interactive display screen information to the display generation logic **221** or the display generation logic **221** may query the machine learning data store **214** to obtain the interactive display screen information. Upon obtaining the interactive display screen information, the display generation logic **221** generates the physical display screen that illustrates the association of one or more anomalous events and/or a comparison of one or more reference models of events that constitute known anomalous behaviors with an association of one or more observed events. In some embodiments, the display screen may contain the particulars of the events.

The UI logic **222** is responsible for receiving requests for the generation of an interactive display screen, requests to display particulars of an event and/or requests to generate signatures (e.g., reference models).

FIG. **2** also illustrates optional reference model generators **243**$_1$-**243**$_2$ attached to sources connected to the network **240**. The reference model generator **243**$_1$ may be connected to (or part of) the TDS **260**$_2$. The reference model generator **243**$_1$ may generate one or more reference models based on network traffic analyzed by the TDS **260**$_2$. The one or more reference models may be transmitted to the MDVS **200** through the network **240** and stored in either the event log **232** or the machine learning data store **214**. Similarly, the reference model generator **243**$_2$ may generate reference models based on data supplied to the management system from a network administrator and/or one or more sources, for example, the endpoint devices **250**$_1$ and/or **250**$_2$, one or more TDSes **260**$_1$-**260**$_3$ and/or the cloud computing services **241**. The generated reference models may be transmitted to the MDVS **200** through the network **240** and stored in either the event log **232** or the machine learning data store **214**.

Referring to FIG. **3**, an exemplary embodiment of a logical representation of the MDVS of FIG. **2** is shown. The MDVS **200** includes one or more processors **300** that are coupled to communication interface logic **301** via a first transmission medium **320**. Communication interface **301** enables communications with endpoint devices **250**$_1$ and/or **250**$_2$, one or more TDSes **260**$_1$-**260**$_3$, the cloud computing services **241** and/or the management system **242** of FIG. **2**. According to one embodiment, communication interface **301** may be implemented as a physical interface including one or more ports for wired connectors. Additionally, or in the alternative, communication interface logic **301** may be implemented with one or more radio units for supporting wireless communications with other electronic devices.

The processor(s) **300** is further coupled to the persistent storage **310** via transmission medium **325**. According to one embodiment of the disclosure, persistent storage **310** may include (a) the machine learning engine **210**, including the machine learning logic **211** and/or the machine learning data store **214**; (b) the UI rendering subsystem **220** that includes the display generation logic **221** and the UI logic **222**; and (c) the event log engine **230** including the event log control logic **231** and the event log **232**. Of course, when implemented as hardware, one or more of these logic units could be implemented separately from each other.

III. Reference Model Generation

Referring to FIG. **4**, an exemplary portion of data received by the event log engine **230** expressed in XML is shown. As described above, the event log control logic **231** receives data transmitted by the one or more sources over the network **240** pertaining to one or more events and the particulars of the events. FIG. **4** illustrates one embodiment of data of events and particulars of the events received by the event log control logic **231**. The data illustrated in FIG. **4** is stored in the event log **232** until it is gathered by the gathering logic **212** (discussed below).

FIG. **4** illustrates details of a first event observed at a time having a timestamp of "200." For example, lines 3-12 state one or more attributes of the process information of a first event at a time having a timestamp value of "200" detailing: (1) the value of the event ("<value>"); (2) the process identification of the event ("<pid>"); (3) the parent process identification of the event ("<ppid>"); (4) the parent name of the event ("<parentname>"); (5) the file size of the event ("<filesize>"); (6) the hash value (e.g., a particular message digest (MD5) hash value) of the event ("<md5sum>"); (7) the securer hash algorithm (SHA) value of the event ("<sha1sum>"); and (1) the file identification of the event ("<fid>"). Similarly, lines 13-20 and 21-26 recite event particulars of a second and third event at times having timestamp values of "300" and "350," respectively.

Based on the data illustrated in FIG. **4**, a reference model may be generated by the reference model generation logic **215** of FIG. **2**. The generation of a reference model may be triggered, for example, at predetermined time intervals, after receipt of a predetermined amount of data from the network **240**, and/or manually by a system administrator or the like. Upon the triggering of the generation of a reference model the gathering logic **212** gathers the data illustrated in FIG. **4** and passes the data to the reference model generation logic **215**. Alternatively, the data illustrated in FIG. **4** may be gathered by the gathering logic **212** and passed to the machine learning logic **211** which will generate an association of potentially malicious events for the matching logic **213** to use in an exploit detection process (discussed below).

Referring to FIG. **5**, an exemplary portion of data generated by either the reference model generating logic **215** or the machine learning logic **211** expressed in XML is shown. As mentioned above, the gathering logic **212** gathers the data illustrated in FIG. **4** and may pass the data to the reference model generating logic **215**. The reference model generating logic **215** generates a reference model for use in an exploit detection process. The generated reference model may be expressed in XML as illustrated in FIG. **5** and subsequently stored in the machine learning data store **214**. Alternatively, FIG. **5** may represent an association of potentially malicious events that will be used by the matching logic **213** in an exploit detection process, such as the exploit detection process performed by the matching logic **213** illustrated in FIGS. **6**-**7**C.

The modifications to the data as illustrated in FIG. **4** to obtain the data as illustrated in FIG. **5** provide indicators of the beginning and end of event data (e.g., "<nodes>") as well as the relationship (e.g., "<edge>") between two events. The modifications may be performed by either the reference model generation logic **215** or the machine learning logic **211**.

IV. Applications of Reference Model(s)

A. Improved Exploit Detection

Referring now to FIG. **6**, an exemplary illustration of a comparison of a reference model of an association of known malicious events with an association of potentially malicious observed events is shown. The machine learning logic **211** may perform an exploit detection process by performing the comparison illustrated in FIG. **6**. The exploit detection process may be triggered, for example, at predetermined time intervals, after receipt of a predetermined amount of data from the network **240**, and/or manually by a system administrator or the like.

The determination of selecting which reference model(s) to use in a comparison such as that illustrated in FIG. **6** is based on one or more factors. Examples of factors include, but are not limited or restricted to, the infection type of one or more events included in the received data (the association of potentially malicious observed events), the type of a file included in the received data and/or the most commonly matched reference models. Alternatively, the received data may be compared to all of the reference models.

Upon the triggering of the exploit detection process, the gathering logic **212** of the machine learning logic **211** initially gathers the data received over the network **240** and stored in the event log **232**. The gathering logic **212** also gathers the one or more reference models that will be used in the comparison. The matching logic **213** of the machine learning logic **211** compares the received data and the one or more reference models gathered by the gathering logic **212**.

In FIG. **6**, the interactive display screen **600** illustrates a side-by-side comparison of two nodal diagrams; the left side being the reference model **620** and the right side being an association of observed potentially malicious events **630** ("the association **630**"). The reference model **620** represents an association of known or observed events and the relationships between the events. The observations or knowledge is such that the event and/or relationship was observed and/or known to have occurred with at least a certain probability. The reference model generation logic **215** of FIG. **2** may generate reference models such as reference model **620** from one or more of the data stored in the machine learning data store **214**, the data stored in the event log **232** and/or data received over the network **240**.

The events Event_**1** **602**, and Event_**2** **603** through Event_m **604** were observed as a result of the performance of an action or operation caused by the Process_A **601**. The events appearing in the reference model **620** are present as a result of one or more events or relationships being deemed at least anomalous, where one or more events or relationships may have been deemed malicious. In one embodiment, the Process_A **601** may have been deemed malicious by the TDS **260**$_1$ of FIG. **2** and such information transmitted to the MDVS **200**. In some embodiments, all behaviors caused by one malicious event may be considered malicious while in other embodiments, only a subset of the events caused by a malicious event may be deemed malicious.

Referring to the association **630**, the solid lines appearing in the association **630** signify that the events and/or relationships (i.e., the line connecting two events) were observed with at least a first confidence (e.g., observation that the event occurred or existed exceeds a first predetermined probability threshold). The dotted lines appearing in the association **630** signify that the events and/or relationships were observed with a second confidence, wherein the second confidence is different and less than the first confidence.

In the comparison performed by the matching logic **213** as illustrated in FIG. **6**, some events and/or relationships may be equivalent in both the reference model **620** and the association **630**. As is illustrated, the events Event_**1** **602** and Event_**2** **603** appear in both the reference model **620** and the association **630**. In addition, the machine learning logic **211** may infer that one or more events and/or relationships were observed and should be included in the association **630** based on the reference model **620**. For example, the machine learning logic **211** may "learn" that when two events are observed, a third typically is as well and therefore infer that the third event was observed, adding it to association **630**. The concept of the machine learning logic **211** learning when events and/or relationship are likely to have be observed by recognizing trends and patterns based on the data stored in the machine learning data store **214**, stored in the event log **232** and/or received over the network **240** will be explained in detail along with the discussion of FIGS. 7A-7C below.

Referring to FIGS. 7A-7D, exemplary diagrams illustrating the exploit detection process performed by the matching logic **213** comparing an association of potentially malicious observed events with a reference model of known malicious events are shown. The changes seen between FIG. **7**A to FIG. **7**B and from FIG. **7**B to FIG. **7**C illustrate one embodiment of a process the machine learning logic **211** may perform to determine whether at least a portion of the association of potentially malicious observed events matches with one or more reference models. In one embodiment, the progression from FIG. **7**A to FIG. **7**B to FIG. **7**C may be considered the development of one interactive display screen. Alternatively, FIGS. **7A-7C** may be considered separate interactive display screens providing a viewer three different perspectives of the potentially malicious events and/or relationships included within the association of potentially malicious events (the right side of the interactive display screen). The embodiment in which FIGS. **7A-7C** may be interactive display screens will be discussed below.

The following discussion of FIGS. **7A-7C** will explain an embodiment wherein the three figures illustrate the exploit detection process performed by the machine learning logic **211**. In addition, the discussion of the changes seen from FIG. **7C** to FIG. **7D** will explain the enhancement of a reference model based on the data transmitted to the MDVS **200**.

Referring to FIG. **7A**, an initial stage of the exploit detection process is shown. The exploit detection process includes a comparison **700** that includes the reference model **730** and the association of potentially malicious events **740** ("the association **740**"). The reference model **730** includes the event 1.exe **701** that is seen to cause the performance of an action or operation in the events 1_M.exe **702**, "hidden files" **703**, "tampered files" **704**, "www.web1.com resolved to 199.16.199.2" **705**, "199.16.199.2" **706**, firefox.exe **707** and C:/Windows/explorer.exe **708**.

In addition, the reference model **730** details the relationships between the events. For example, FIG. **7A** provides that the event 1.exe **701** caused the creation of a mutex to be performed that resulted in the observation of the event 1.exe_M **702**. Likewise, it is seen that the event 1.exe **701** exhibited malicious action that resulted in various hidden files **703**. Similarly, the relationships between the event 1.exe **701** and the other events included in the reference model **730** are illustrated in the comparison **700**.

The association **740** includes the event 1.exe **701** that is seen to cause the performance of an action or operation resulting in the events 1_M.exe **721**, "hidden files" **722**, "tampered files" **723**, "disabled taskmanager" **724** and C:/Windows/4.exe **725**. In contrast to the reference model **730**, not all of the relationships between the events included in the association **740** are illustrated in FIG. **7A**. The association **740** shown in FIG. **7A** may not include enough data for the MDVS **200** to initially recognize all events and relationships with at least a first confidence, as mentioned above. As illustrated in FIG. **7A**, the machine learning logic **211** may not initially have access to data allowing the machine learning logic **211** to determine relationships between the event **720** and the events **722**, **723** and **725** with at least the first confidence.

Therefore, as one embodiment, FIG. **7A** illustrates the first stage in the process of generating the association **740** that is shown in FIG. **7C**. For example, the data used to generate the association of FIG. **7A** may have been transmitted to the MDVS **200** from the TDS **260**$_1$. The TDS **260**$_1$ may have, for example, processed a portion of network traffic it received in one or more virtual machines and observed, among others, the events and relationship included in the association **740** of FIG. **7A**. One or more of the events and/or relationships included in the association **740** of FIG. **7A** may be been deemed malicious, prompting the TDS **260**$_1$ to transmit the observations to the MDVS **200**.

Referring to FIG. **7B**, a second stage of the exploit detection process is shown. The association **740** illustrated in FIG. **7B** is seen to have two additional events included compared to the association **740** of FIG. **7A**. In particular, the two events, "www.web1.com resolves to 199.16.199.2" **750** and "199.16.199.2" **751**, are illustrated using dotted lines. In the embodiment of FIGS. **7A-7C**, dotted lines are intended to represent that the events and/or relationships were observed with a second confidence, meaning that the data available to the machine learning logic **211** did not provide as much support for the occurrence or existence of the events illustrated using dotted lines as the data did for the occurrence or existence of the events illustrated using solid lines.

Alternatively, the dotted lines may represent that the event was not detected at any one source but instead is an inference from the event's appearance in the reference model **730**. For example, the dotted box surrounding the "www.web1.com resolves to 199.16.199.2" event **750** may represent that no source connected to the MDVS **200** via the network **240** observed the "www.web1.com resolves to 199.16.199.2" event **750**. Instead, based on the similarities between the association **740** and the reference model **730**, the matching logic **213** inferred that the "www.web1.com resolves to 199.16.199.2" event **750** should be included and may have occurred but its observance did not occur.

In one embodiment, the data may have only provided one source of evidence of the occurrence of existence of the events illustrated using dotted lines whereas the first confidence requires Y or more sources of evidence are state that an event occurred or existed (wherein $Y \geq 2$). Alternatively, or in addition, the dotted lines may represent that the machine learning logic **211** has inferred that the events illustrated using dotted lines occurred or existed. Through machine learning, the machine learning logic **211** may have recognized that the events illustrated using dotted lines typically occur or exist when one or more of the events illustrated using solid lines were observed and therefore infer that it is likely the events illustrated dotted lines occurred or existed but were not observed with the first confidence. For example, the machine learning logic **211** may recognize that when an executable file (e.g., 4.exe **720**) generates a mutex which is followed by the hiding of files and tampering with network settings, it is likely that the website "www.web1.com" resolves to the IP address "199.16.199.2" and source (e.g., TDP **260**$_1$) connected to the IP address "199.16.199.2" based on the reference model **730**.

Referring to FIG. **7C**, the association **740** is fully illustrated such that the relationships between the event 4.exe **720** and the events 1_M.exe **721**, "hidden files" **722**, "tampered files" **723**, "disabled taskmanager" **724**, "www.web1.com resolved to 208.73.211.247" **750**, "208.73.211.247" **751** and C:/Windows/4.exe **725** are present in the comparison **700**. As was discussed regarding FIG. **7B**, the machine learning logic **211** may infer one or more relationships based on at least a comparison **700** of the association **740** with the reference model **730**. Therefore, the comparison **700** as illustrated in FIG. **7C** provides the matching logic **213** the association of the event 4.exe **720** with the events **721-725**, **750** and **751** allowing the matching logic **213** to make a determination as to whether the association **740** matches with the reference model **730**.

Based on FIGS. **7A-7C**, the matching logic **213** may ascertain what malicious events occurred or existed, the relationships between the one or more events as well as the confidence of the machine learning logic **211** of the occurrence or existence of a particular event and/or relationship. The comparison **700** in FIGS. **7A-7C** performed by the matching logic **213** to compare the association of observed and/or inferred events with a reference model allowing the matching logic **213** to determine the extent of malicious activity that may have occurred and what files, processes, locations, etc. may have been affected.

Furthermore, the matching logic **213** may determine whether a correlation exists between the reference model **730** and the association **740** depending on predetermined characteristics and thresholds. For example, the matching logic **213** may find a correlation when Z specific events are found to match in the reference model **730** and the association **740** (wherein Z is a predetermined number). Alternatively, the matching logic **213** may determine a correlation exists if a predetermined number of events and/or relationships are found to match between the reference model **730** and the association **740**. In yet another embodiment, the matching logic **213** may find a correlation if a predetermined number of events and/or relationships are found to match and one or more events and/or relationships are not present in both of the reference model **730** and the association **740**. Any combination of the above scenarios may be used to determine whether a correlation is present between the reference model **730** and the association **740**. The machine learning logic **211** may store these correlations in the machine learning data store **211** as a way of "learning" when one or more malicious events and/or relationships may be inferred.

Referring to FIG. **7**D, an enhancement to the reference model **730** is shown. The event "Disabled TaskManager **724**" has been added to the reference model **730** and is illustrated with a dotted and dashed line. In addition, the relationship between the process 1.exe **701** and the event "Disabled TaskManager **724**" is also present in the reference model **730** similarly illustrated with a dotted and dashed line. As a result of the data transmitted to the MDVS **200**, and optionally, in addition to the data stored in the event log **232** and/or the machine learning data store **212**, the machine learning logic **211** may determine that there is sufficient correlation between an event and/or relationship and a reference model such that the event and/or relationship should be added to the reference model.

In one embodiment, a "sufficient correlation" may include the event and/or relationship appearing within a grouping of events a predetermined number of times. For example, if the event "Disabled TaskManager **724**" appears X number of times (wherein X is a predetermined threshold) when a process (e.g., 4.exe **720**) generates a mutex, hides files and tampers with network settings, the event "Disabled Task-Manager" **724** will be added to the reference model including those events. Referring back to FIG. **1**, the addition of event "Disabled TaskManager **724**" and the relationship between the between the process 1.exe **701** and the event "Disabled TaskManager **724**" is illustrated in FIG. **1** as "exploit detection feedback" from block **130** to block **120**. The addition of one or more events and/or relationships to a reference model constitutes exploit detection feedback as illustrated in FIG. **1**. The one or more events and/or relationships determined by the matching logic **213** and/or the machine learning logic **211** to be added to one or more reference models may be transmitted to the reference model generation logic **215**. The gathering logic **212** may gather the reference models to be updated from the machine learning data store **214**. The reference model generation logic **215** may then perform an updating process to the one or more gathered reference models by adding the one or more events or relationships into the one or more reference models. The reference models that are to be updated may be determined by gathering all reference models having one or more common events and/or relationships with the reference model used in the comparison or all reference models included in the machine learning data store **214**. Alternatively, reference models to be updated may be selected based on file types included in the reference models and/or a source that observed the events included in the reference models (e.g., email TDS, web TDS, file TDS and/or mobile TDS).

The enhanced reference model **730** may be used to update and/or allow for more particularized exploit detection. For example, the enhanced reference model **730** may be used by, among others, the management system **242** to further configure or reconfigure one or more of the sources (e.g., the endpoint device **250**$_1$ and/or the TDS **260**$_1$). The reconfiguration or further configuration may entail, for example, configuring the one or more sources to search one or more pieces of network traffic for an extended amount of time, search the one or more pieces of network traffic multiple times and/or search for different malware exploits and/or certain events and/or relationships.

Alternatively, or in addition to, the enhanced reference model **730** may provide a means for updating one or more correlation rules for classifying malware (e.g., updating signatures or rules for determining whether an object of network traffic is suspicious and/or configuring and/or reconfiguring one or more virtual machines (VMs) included in one or more sources). Such updated signatures may be more robust due to the more complete picture of a malware exploit the updated signature provides. In one embodiment, the enhanced reference model **730** may provide improved alerts and recognition of malware based on the enhancement.

Referring to FIG. **8**, an exemplary illustration of a comparison **800** of reference models **820** and **821** with an association of potentially malicious observed events is shown. Similar to FIGS. **7**A-**7**C, the comparison **800** includes a left side and a right side. However, in contrast to FIGS. **7**A-**7**C showing a single reference model, the left side of the comparison **800** includes the reference model **820** and the reference model **821**. One embodiment of the generation process of the association of potentially malicious events **822** (the association **822**) is similar to the embodiment describing FIGS. **7**A-**7**C. Furthermore, in the embodiment of FIG. **8**, the machine learning logic **211** may infer events and/or relationships from two reference models.

In FIG. **8**, the association **822** is seen to have solid lines illustrating the Event_A_**1 802** and the Event_G_**1 805**. In addition, the relationship connecting the Process_C_**1 810** with the Event_A_**1 802** and Event_G_**1 808** are illustrated using solids lines. Therefore, FIG. **8**, illustrates the Event_A_**1 802** and the Event_G_**1 808** and the connections (i.e., relationships) between the Process_C_**1 810** and the events Event_A_**1 802** and Event_G_**1 808** were observed with at least a first confidence by one or more of the sources connected to, for example, the network **240** of FIG. **2**.

Furthermore, the events Event_D_**1 805** and Event_F_**1 807** as well as the connections between the Process_C_**1 810** and the events Event_D_**1 805** and Event_F_**1 807** are illustrated as dotted lines meaning these events and connections were inferred from the Process_A_**1 801** and/or the Process_B_**1 809**. As can be seen in FIG. **8**, the reference model **820** includes the Event_D_**1 805**. The reference model **821** includes the Event_F_**1 807**. In addition, not all events present in one or more of the reference models need to be inferred as occurring within the received data. For example, the events Event_B_**1 803** and Event_C_**1 804** was not inferred by the machine learning logic **211** as having occurred with the association **822**. In one embodiment, the received data along with the reference models available to the machine learning logic **211** may not have supported such an inference.

B. Malware Family Reference Model Generation

Malware family generation is the generation of comprehensive signatures used to identify one or more anomalous, or more specifically malicious, files, processes, etc., and/or relationships that are related through, among others, the evolution of a malware, a common point of attack or attack pattern (e.g., multiple pieces of malware gaining unauthorized access to the same file or process within an operating system), a common method of entering a network or electronic device (e.g., embedded software in an email or embedded software in a portable document format (PDF) file), a common targeted vulnerability (e.g., a common exploit kit), a common targeted information and/or a common targeted unauthorized access point. The generation of a malware family reference model may be triggered, for example, at predetermined time intervals, after receipt of a predetermined amount of data from the network **240**, and/or manually by a system administrator or the like.

Upon the triggering of the generation of a malware family reference model, the gathering logic **212** of the machine learning logic **211** initially gathers a plurality of appropriate reference models stored in the machine learning data store **214**. The gathering logic **212** determines which reference models are appropriate for generation of a malware family reference model based on one or more characteristics of the triggering event and/or the plurality of reference models currently stored in the machine learning data store **214**. The matching logic **213** of the machine learning logic **211** compares the received data and the one or more reference models gathered by the gathering logic **212**.

In one embodiment, the reference models stored in the machine learning data store **214** may all include one or more common events and/or relationships and therefore all reference models may be used to generate a family malware reference model. Alternatively, appropriate reference models for generating a malware family reference model may be selected based on file types included in the reference models and/or a source that observed the events included in the reference models (e.g., email TDS, web TDS, file TDS and/or mobile TDS). Furthermore, if a network administrator manually triggers the generation of a reference model, the network administrator may manually select one or more of the above characteristics for the gathering logic **212** to use in its determination of what reference models in the machine learning data store **214** are appropriate to include in the reference model generation.

Once the reference models that will be used to generate a malware family reference model have been gathered by the gathering logic **212**, the reference models are passed to the reference model generating logic **215**. As will be discussed below in relation to FIG. **9**, the reference model generating logic **215** generates a malware family reference model by computing the mathematical union between the plurality of reference models gathered by the gathering logic **212**.

Referring to FIG. **9**, an exemplary illustration of a process of generating a malware family reference model is shown. The generation process **900** performed by the reference model generation logic **215** of FIG. **2** includes a left side and a right side. The left side includes two reference models, the reference models **930** and **931**. The reference model **930** includes the Process_A_**2 901** and the events Event_A_**2 902**, Event_B_**2 903**, Event_D_**2 905** and Event_E_**2 906**. The reference model **931** includes the Process_B_**2 908** and the events Event_A_**2 902**, Event_B_**2 903**, Event_C_**2 904**, Event_E_**2 906** and Event_F_**2 907**.

The malware family reference model **940** has been generated from the reference models **930** and **931**. The reference model generation logic **215** compares two or more reference models in order to generate a malware family reference model. The reference model generation logic **215** generates the malware family reference model by placing all distinct events in the two or more reference models compared (e.g., the mathematical union of the two or more reference models compared) into the malware family reference model (e.g., the malware family reference model **940**).

As illustrated in FIG. **9**, the malware family reference model **940** contains all distinct events included in the reference models **930** and **931**. In particular, the reference model generation logic **215** generates the malware family reference model **940** by placing the events the reference model **930** has in common with the reference model **931** (the events Event_A_**2 902**, Event_B_**2 903**, Event_C_**2 904** and Event_E_**2 906**) in the malware family reference model **940**. The reference model generation logic **215** also places any events included in the reference model **930** in the malware family reference model **940** that are not included in the reference model **931** (the events Event_D_**2 905**). To conclude, the reference model generation logic **215** places any events included in the reference model **931** in the malware family reference model **940** that are not included in the reference model **930** (the events Event_F_**2 907**). The process of placing events in common or events included in less than all of the reference models compared to generate a malware family reference model may be done in any order.

The malware family reference model **940** also includes the process Process_C_**2 910**. This process may be equivalent to any of the processes included in one or more of the reference models compared to generate the malware family reference model (e.g., the processes Process_A_**2 901** and Process_B_**2 908**).

The reference models used by the machine learning logic **211** to generate malware family reference models may be stored in the machine learning data store **214** and/or the event log **232**, and/or received over the network **240**. In addition, signatures generated in accordance with the discussion of FIGS. **14**A and **14**B may be used in the generation of malware family reference models.

C. Visualization

As mentioned above, interactive display screens comprising FIGS. **7A-7C** may be generated by the display generation logic **211** of the UI rendering subsystem **220**. In such an embodiment, the interactive display screens illustrating FIGS. **7A-7C** may give a viewer a side-by-side visual comparison of a reference model and an association of potentially malicious events (e.g., at least a portion of data received over the network **240**). A side-by-side visual comparison may allow a viewer to understand the source of the anomalous behavior as well as determine what files, processes, network settings, etc., and/or relationships that may have been affected.

Referring to now FIG. **10**, an exemplary embodiment of an interactive display screen **1000** for display of associated events and/or particulars of the associated events used in generating the interactive display screens of FIGS. **12-14**B is shown. Herein, rendered by the UI rendering subsystem **220**, the interactive display screen **1000** features a plurality of display areas **1010** and **1030** that illustrate information directed to events and particulars of the observed events over a time period by the one or more sources (the endpoint devices **250**$_1$ and **250**$_2$, the TDSes **260**$_1$-**260**$_3$ and/or the cloud computing services **241** of FIG. **2**) and or the management system **242** of FIG. **2**.

According to one embodiment, the display area **1010** displays a plurality of entries **1020**$_1$-**1020**$_R$ (R≥1, where R=9 for this embodiment) that provides information directed to observed events, where one or more events are anomalous or malicious. As shown, each row of entries (e.g., row **1020**$_1$) rendered by the UI rendering subsystem **220** features a plurality of fields, including one or more of the following: (1) a date and time of the observation **421**; (2) an event name **422**; (3) a process identification (PID) **423** (if applicable); (4) a path directing the viewer to the location at which the event may be located **424**; and/or (5) a source that observed the event (e.g., email TDS, web TDS, file TDS and/or mobile TDS).

A second area **1030** may be configured to allow selection of one or more observed potentially malicious events for viewing on a second visual representation. In one embodiment, when an observed event has been selected, the row may appear highlighted as is seen in FIG. **10**. The buttons **1040** and **1041** enable viewing of an interactive visual representation (e.g., nodal diagram) of the selected events as they relate to one or more events within the display area **1010** and/or as they compare to one or more reference models of known anomalous or malicious behaviors. For example, based on the exemplary embodiment of FIG. **10** in which entry **1020**$_2$ is selected, activation of the button **1040** labeled "Exploit Visualization" would subsequently present an interactive display screen of the relationships of the observed event represented in entry **1020**$_2$ to other events, including perhaps one or more events appearing in display area **1010** (to be described below). Similarly, activation of the button **1041** labeled "Timeline Visualization" would subsequently present a second interactive display screen of the relationships of the observed event represented in the selected entry **1020**$_2$ to other events, including perhaps one or more events appearing in display area **1010** (to be described below). Alternatively, activation of the button **1042** labeled "Generate Signature" would request the machine learning logic **211** of FIG. **2** to generate a signature based on the selected event and, in one embodiment, any subsequent events branching from the selected event (to be discussed in detail below).

One or more interactive display screens may be comprised of, among other things, a top-down nodal or tree diagram (e.g., an "exploit visualization") or a left-to-right nodal or tree diagram (e.g., "a timeline visualization"). A time axis is illustrated in FIG. **12** and will be discussed below. Particulars of the events may be included to provide a detailed understanding of, among other things, where events are located within an electronic device or various methods of identifying one or more events (e.g., file/process name or PID). In addition, the interactive display screen may provide the viewer an understanding of how the event was detected by color-coding the events or providing various line formatting (e.g., dashed lines, solid lines, double lines, etc.) based on, for example, the portion of a TDS or endpoint device that observed the event. Alternatively, the illustration of the events may be color-coded based on the type of event. Additionally, the display may be a static visual representation of the one or more relationships between one or more events.

In addition, a rank may be assigned to the events included in a nodal diagram. For example, when an association of events are illustrated as a top-down nodal diagram, each row of events may be considered to have the same rank, wherein a first event appearing above a second event has a higher rank than the second event. Alternatively, when an association of events are illustrated as a left-to-right nodal diagram, each column of events may be considered to have the same rank, wherein a first event appearing to the left of a second event has a higher rank than the second event.

Referring to FIG. **11**, an exemplary portion of data generated by either the reference model generating logic **215** or the machine learning logic **211** expressed in XML is shown. As described above, the machine learning logic **211** generates interactive display screen information for the visual representation of one or more relationships between one or more events and the particulars of the events. FIG. **11** illustrates one embodiment of data detailing the relationship of a first event to a second event and the relationship of the first event to a third event. For example, lines 5-6 denote the first and second events (node 1 and node 2 as "process_1" and "registry_1," respectively). Line 9 denotes the relationship before the first and second events (edge 1 as "node_1.created/changed-properties.node_2"). Similarly, Lines 12-20 represent details of the relationship between the first event and the third event.

The data illustrated as FIG. **11** may represent the interactive display screen information used by the display generation logic **221** to generate a display for viewer. For example, the data illustrated in FIG. **11** is used by the display generation logic **221** to generate a portion of FIGS. **12** and **13** as discussed below.

Referring now to FIG. **12**, an exemplary illustration of a first embodiment of an interactive display screen for display of associated events and particulars of the associated events is shown. In FIG. **12**, the interactive display screen **1200**, depicted as a nodal diagram, illustrates the associated events at a high-level allowing a viewer to obtain an understanding of the relationships between one or more observed events wherein one or more anomalous behaviors are present. An anomalous behavior may be (i) a suspicious event or relationship that was observed by one or more of the sources (the endpoint devices **250**$_1$ and **250**$_2$, the TDSes **260**$_1$-**260**$_3$ and/or the cloud computing services **241**) or (ii) a malicious event or relationship observed by one or more of the sources. For example, a malicious event may cause performance of one or more actions that result in one or more malicious behaviors and/or one or more non-malicious behaviors. In general, the depiction of a first event appearing vertically above a second event is intended to illustrate that the first event was observed at a time prior to the second event. Similarly, a depiction of a second event appearing vertically equivalent (e.g., aligned in a row) with a third event, wherein the second event appears to the left of the third event, is intended to illustrate that the second event was observed at a time prior to the third event. It should be noted that exceptions may occur and labeling of such exceptions (e.g., by the use of numbering events and/or relationships) may be used to denote such exceptions to the viewer (numbering of exceptions will be illustrated in and described along with FIG. **13**).

In FIG. **12**, the Parent_Process_**1** **1201** is seen to cause an action or operation resulting in the Process_**1** **1202** at a first time. In one embodiment, the Parent_Process_**1** **1201** may be a malicious event and starting the Process_**1** **1202** may constitute a malicious action or operation (e.g., if the Process_**1** **1202** is also a malicious event and/or if the starting of the Process_**1** **1202** was not a normal function of the electronic device on which the action or operation occurred (or virtual machine performing processing of the Parent_Process_**1** **1201**)). Alternatively, the Parent_Process_**1** **1201** and/or the Process_**1** **1202** may be non-malicious events and the starting of the Process_**1** **1202** may be construed as a non-malicious action or operation.

In addition, the Process_**1** **1202** causes the performance of one or more actions or operations that result in the events including: (i) the Registry_**1** **1203**; (ii) the File_**1** **1204**; (iii) the File_**2** **1205**; and (iv) the Process_**2** **1206**. Similarly, the File_**1** **1204** is depicted as causing the performance of an action or operation that results in the Process_**3** **1207**. Furthermore, the Process_**2** **1206** is depicted as causing the performance of an action or operation that results in the File_**3** **1208**.

Therefore, according to one embodiment, when the interactive display screen **1000** of FIG. **10** is viewed and the button **1440** ("Exploit Visualization") is activated, the interactive display screen **1200** is displayed using the information included in the interactive display screen **1000** which may be derived from interactive display screen information expressed as XML files similar to FIG. **11**.

As mentioned above, a time axis **1210** is illustrated in FIG. **12**. The time axis **1210** illustrates the embodiment wherein an interactive display screen (e.g., the interactive display screen **1200**) is configured to illustrate an order of events in a sequential manner according to one or more time axes. The time axis **1210** shows that the events in the interactive display screen **1200** are ordered in a top-to-bottom and left-to-right manner according to the time of performance of the one or more actions or operations that resulted in the events **1201**-**1208**. For example, the event **1202** is illustrated below the event **1201** implying that the performance of the one or more actions or operations that resulted in the event **1201** occurred prior in time to the one or more actions or operations that resulted in the event **1202**. Similarly, the event **1203** is illustrated to the left of the event **1204** implying that the performance of the one or more actions or operations that resulted in the event **1203** occurred prior in time to the one or more actions or operations or behaviors that resulted in the event **1204**. In another embodiment, a time axis may only comprise one axis (e.g., horizontal such as left-to-right, vertical such as top-to-bottom, etc.). Alternatively, a time axis may not be included in an interactive display screen.

In addition, a time axis may be present in an interactive display screen illustrating a left-to-right nodal diagram (e.g., an embodiment in which FIG. **7**D may be used as an interactive display screen). As stated above, when a time axis is present in an interactive display screen illustrating a left-to-right nodal diagram, the time axis may comprise a single axis (e.g., only top-to-bottom) or may comprise two time axes (e.g., top-to-bottom and left-to-right).

Referring back to FIG. **2**, the machine learning engine **210** analyzing observed events comprising an exploit after the occurrence of the exploit may fail to determine the source of infection. Even if the events are observed in their entirety, sometimes the voluminous manner of the observed events (events comprising both malicious events and non-malicious events) may make the determination of the presence of an exploit and/or malware difficult. Being able to compare the observed events with a reference model assists in sifting through the data and discovering the origin of infection. For example, a user may have browsed to a well-known Uniform-Resource Locator (URL) that was compromised and unintentionally downloaded malware on an endpoint. Subsequently, the malware may have stolen data and uploaded the stolen data to a foreign server. A reference model stored in the MDVS **200** may contain the sequence of such events. If the matching logic **213** of the MDVS **200** is able to match the observed events with a portion of the reference model, the machine learning logic **211** may infer that all of the events occurred although not all of the events were observed based on the sequential ordering of the reference model. The matching logic **213** may determine that one or more events in the reference model were not observed, or were not observed with at least a first confidence. For example, based on the sequential ordering of the events and the time axis of the reference model, the machine learning logic **211** may infer that an event_B occurred prior to an event_C but subsequent to an event_A, although event_B was not observed by at least one source (e.g., the endpoint device $\mathbf{250}_1$).

In addition, the machine learning logic **211** may trace the root cause of the exploitation back to the initial visit to the compromised URL based on a time axis and the sequential ordering of the events in the reference model. In one embodiment, the presence of a time axis on an interactive display screen may allow a viewer, such as a network administrator, to visually understand which event was the root cause of the exploit.

Referring to FIG. **13**, an exemplary illustration of a detailed embodiment of the interactive display screen of FIG. **12** is shown. In addition to events **1201**-**1208** of FIG. **12**, interactive display screen **1300** illustrates events **1301**-**1306** corresponding to the Registry_**2**, the Registry_**3**, the Registry_**4**, the File_**4**, the Folder_**1** and the File_**5**, respectively. In particular, the Process_**3** **1207** causes the performance of one or more actions or operations that result in events **1301**-**1306**.

In addition to providing a visual representation of how the events **1201**-**1208** and **1301**-**1306** are related, the interactive display screen **1300** displays one or more particulars of each event. For example, the path ("c:/doc1/local1/temp/4.exe") and the PID ("**1676**") are displayed for the Process_**1** **1202**. The particulars displayed for each event may differ, for example, only the path of an event may be displayed as is the case with the File_**1** **1204** in the present embodiment.

Furthermore, the interactive display screen **1300** provides the viewer with the relationship between two events and the timing of the observation of the relationship. For example, the relationship between the Process_**1** **1202** and the File_**1** **1208** is the third relationship generated of the relationships displayed in the interactive display screen **1300**. In addition, the relationship between the Process_**1** **1202** and the File_**1** **1208** is seen to be "created." Therefore, from the interactive display screen **1300**, a viewer can easily determine that, of the events and relationships included in the display screen **1300**, the operation of the Process_**1** **1202** creating the File_**1** **1204** was the third relationship created. The Process_**1** **1202** then opens the File_**2** **1205** and starts the Process_**3** **1207** (which is the File_**1** **1204** being launched as a process as the File_**1** **1204** is an executable file). In addition, the Process_**1** **1202** starts the Process_**2** **1206** as the seventh relationship.

The Process_**2** **1206** deletes the File_**3** **1208** as the eighth relationship. Subsequently, the Process_**3** **1207** sets the name/value pair for the Registry_**2**, the Registry_**3** and the Registry_**4** as the ninth, tenth and eleventh relationships respectively. The Process_**3** **1207** then opens the Registry_**5**, the Folder_**1** and the File_**5** as the twelfth, thirteenth and fourteenth relationships respectively.

V. Signature Generation

As mentioned above, one embodiment of the invention enables a viewer to generate one or more signatures from the interactive display screens of, for example, FIGS. **10** and

12-14B. In one embodiment, the viewer may select an event and generate a signature based on the event including any events that directly and/or indirectly branched from the selected event. In a second embodiment, the viewer may select a particular grouping of events and generate a signature limited to those selected events. The generated signatures may be stored in the machine learning data store **214** of FIG. **2** to be used in future comparisons of one or more reference models of a plurality of events and at least one or more relationships where at least one of these events and/or relationships is an anomalous behavior or known to be malicious. In addition, signatures generated from a first set of data received from a first endpoint device may be compared to similar signatures generated from a second set of data received from a second endpoint device in order to determine whether an event frequently appears across multiple endpoint devices (e.g., correlated operations or actions across endpoint devices). The frequent appearance of an event across multiple endpoint devices may imply that the event is malicious (e.g., an exploit), or at least suspicious. In addition, the frequent appearance of one or more events across multiple endpoint devices (or other sources that supply data to the MDVS **200**) may indicate that the one or more sources is associated with a malware family.

Referring to FIG. **14**A, an exemplary illustration of a portion of an interactive display screen for enabling a viewer to generate a signature of a selected event, display particulars of the selected event and/or generate an alert for a selected event is shown. FIG. **14**A illustrates a viewer selecting an event (e.g., the Process_**2** **1206** of FIG. **12**) which brings up an overlaying pop-up box **1410** allowing the viewer to select to "Generate Signature **1411**," "Display Info Parameters **1412**" or "Generate Alert **1413**." The selection of "Generate Signature **1411**" enables the viewer to generate a signature (e.g., a reference model) based on the selected event. The signature may include all events that are a direct or indirect branch from the selected event. For example, a viewer selecting "Generate Signature **1411**" for the Process_**2** **1206** may generate a signature including the Process_**2** **1206** and the File_**3** **1208** (as is seen in FIG. **12**). The selection of "Display Info Parameters **1412**" for the Process_**2** **1206** would display an interactive display screen including the information included in the row $\mathbf{1020}_6$ of FIG. **10**. The selection of "Generate Alert **1413**" enables a viewer to generate a rule for the MDVS **200** to issue an alert when the selected event is observed by an endpoint device or other source. Therefore, according to the example in FIG. **14**A, when a viewer selects "Generate Alert **1413**" for the Process_**2** **1206**, the MDVS **200** will issue an alert to the viewer notifying the viewer of the observation of the Process_**2** **1206** at an endpoint device. In one embodiment, the MDVS **200** will issue the alert when the MDVS **200** receives data containing an observation of the Process_**2** **1206**. In a second embodiment, the MDVS **200** may notify the management system **242** of the creation of the rule and the management system **242** may propagate the rule to each source connected to the network **240** (the endpoint devices $\mathbf{250}_1$-$\mathbf{250}_2$, the TDS $\mathbf{260}_1$-$\mathbf{260}_3$ and the cloud computing services **241**).

Referring back to FIG. **1**, the selection of one or more of "Generate Signature **1411**," "Display Info Parameters **1412**" or "Generate Alert **1413**" is equivalent to the "Interactive Display Screen Input" illustrated in FIG. **1**. The interactive display screen input is transmitted from block **150** to block **120**. In particular, the data obtained from the selecting "Generate Signature **1411**" includes the particulars of the selected event (e.g., the Process_**2** **1206** as seen in FIG. **14**A) and potentially the events branching from the selected event and the relationships that connect the selected event and any branched events. This data obtained from the selection of "Generate Signature **1411**" may be stored as a signature/reference model in the machine learning data store **214** for use in future exploit detection processes and/or reference model generation processes.

The selection of "Display Info Parameters **1412**" may result in a query by the gathering logic **212** to the machine learning data store **214** and/or the event log **232** to gather the particulars of the selected process. The machine learning logic **211** may generate interactive display screen information based on the data gathered by the gathering logic **212**. The display generation logic **221** may use the interactive display screen information to generate a display in a layout similar to the display screen of FIG. **10**.

The selection of "Generate Alert **1413**" may result in the gathering of the particulars of the selected process, any events that are branched from the selected event and any relationships connecting the branched events by the gathering logic **212** and the generation of an alert by the machine learning logic **211**.

It should be noted that, although in the above paragraphs information (e.g., the particulars) of branched events and the corresponding relationships may be gathered as well as the selected event, the particulars of only the selected event may be gathered as well. The system may be set up to gather either, or a network administrator may be able to adjust how the system responds to a selection of one or more of "Generate Signature **1411**," "Display Info Parameters **1412**" and/or "Generate Alert **1413**."

Referring to FIG. **14**B, an exemplary illustration of a second embodiment of an interactive display screen for enabling a viewer to generate a signature of a selected event is shown. FIG. **14**B illustrates that a viewer has selected a particular grouping of events (the Process_**3**, the Registry_**2**, the Registry_**3**, the File_**4** and the Folder_**1**) for which the viewer may generate a signature by selecting "Generate Signature **1411**." The generated signature in FIG. **14**B differs slightly from that of FIG. **14**A in the sense that the signature of **14**A may include all of the events branching directly and/or indirectly from the selected from. FIG. **14**B does not include the event File_**5** **1406**. The exclusion of the event File_**5** **1406** may be a result of the viewer knowing whether the event File_**5** **1406** are not malicious and therefore should be not included in a reference model. The selection of "Generate Signature **1411**" in FIG. **14**B has the same effect as discussed in reference to FIG. **14**A above.

Referring to FIG. **15**, is an exemplary portion of the generated signature (corresponding to the selected section in FIG. **14**B) expressed in XML. The data illustrated by FIG. **15** represents the XML generated when a viewer generates a signature from the interactive display screen **1300** as illustrated in FIG. **14**B. As seen in FIG. **14**B, a portion of the interactive display screen **1300** has been manually selected by a user and an input (e.g., clicking of a button on a mouse) allows the viewer to generate a signature by activating the option labeled "Generate Signature" **1411**. The data illustrated in FIG. **15** may be stored in the machine learning data store **214** and used by the reference model generation logic **215** and/or the matching logic **213** to either generate a reference model or perform an exploit detection process, respectively.

In the foregoing description, the invention is described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A system for cyber-attack detection comprising:

one or more hardware processors; and

a non-transitory storage module communicatively coupled to the one or more processors, the storage module comprises logic, upon execution by the one or more processors, that

accesses a first set of information that comprises (i) information directed to a plurality of observed events, each of the observed events being observed during operation of a source device communicatively coupled to the system, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

generates a reference model based on the first set of information, the reference model comprises at least a first observed event, a second observed event, and a first relationship that identifies that the second observed event is based on the first observed event, wherein the first observed event and the second observed event are included in the plurality of observed events,

analyzes a second set of information that is different than the first set of information, the second set of information including a third event and a second relationship,

enhances the reference model by adding the third event or the second relationship to the reference model based on a correlation between the reference model and the second set of information, and

generates an interactive graphical display of at least the reference model that includes the third event or the second relationship,

wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

2. The system of claim **1**, wherein the anomalous behavior includes a first file opened by a first process, wherein the first file is configured to be opened by a second process that is different from the first process and is not configured to be opened by the first process.

3. The system of claim **1**, wherein the generating of the reference model by the logic comprises determining that the first event of the plurality of observed events performed at least one of an action or an operation, the at least one of the action or the operation results in an observance of subsequent events of the plurality of observed events including the second event of the plurality of observed events.

4. The system of claim **1**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

5. A system for cyber-attack detection comprising:

one or more hardware processors; and

a non-transitory storage module communicatively coupled to the one or more processors, the storage module comprises (i) an event log to store information associated with at least a first plurality of observed events and (ii) logic that, upon execution by the one or more processors and in response to a triggering event,

(a) accesses a first set of information that comprises (i) information directed to the first plurality of observed events stored in the storage, each of the first plurality of observed events being observed during operation of a source device communicatively coupled to the system, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

(b) accesses a reference model based on a second plurality of observed events, the reference model comprises at least a first observed event of the second plurality of observed events, a second observed event of the second plurality of observed events, and a first relationship that identifies that the second event is based on the first event, wherein the first observed event and the second observed event are included in the plurality of observed events,

(c) enhances the reference model by adding a third event or a second relationship to the reference model based on a correlation between the reference model and the first set of information, the third event and the second relationship included in the first set of information, and

(d) generates a graphical, interactive display of a comparison of the first plurality of observed events with the reference model that includes the third event of the second relationship, the interactive display including one or more diagrams,

wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

6. The system of claim **5**, wherein a first event of the first plurality of observed events is selectable to (i) provide metadata associated with the first event of the first plurality of observed events; (ii) generate a signature of the first event of the first plurality of observed events; or (iii) generate an alert for the first event of the first plurality of observed events.

7. The system of claim **6**, wherein

at least the first event and a second event of the first plurality of observed events are selectable via the graphical interactive display.

8. The system of claim **5**, wherein the plurality of diagrams include two or more nodal diagrams placed in a side-by-side manner, the nodal diagrams illustrating (i) each event of the first plurality of observed events and each relationship of the first plurality of observed events and (ii) the reference model.

9. The system of claim **5**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a solid line, the solid line representing that the first event of the first plurality of observed events was observed with at least a first confidence.

10. The system of claim **9**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first event of the first plurality of observed events was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

11. The system of claim **5**, wherein the first relationship is illustrated in the one or more diagrams with a solid line, the solid line representing that the first relationship was observed with at least a first confidence.

12. The system of claim **5**, wherein the first relationship is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first relationship was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

13. The computerized system of claim **5**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

14. A computerized method for malware detection comprising:

accessing information that comprises (i) information directed to a plurality of observed events, each of the plurality of observed events being observed during operation of a source device communicatively coupled to the system, and (ii) information directed to one or more relationships identifying that a first observed event is based on a second observed event, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code;

generating an interactive display of at least the first observed event, the second observed event and a relationship identifying that the first observed event is based on the second observed event; and

upon receiving a selection of the first observed event and the second observed event via the interactive display, generating a signature associating the first observed event and the second observed event, wherein combination of at least two of (i) the first observed event, (ii) the second observed event, or (iii) the relationship indicates known a cyber-attack.

15. The method of claim **13**, wherein the signature associated with the first observed event and the second observed event further includes information associated with the relationship to identify that the first observed event is based on the second observed event.

16. The method of claim **13**, wherein the interactive display comprises a nodal diagram illustrating at least the first observed event, the second observed event, and the relationship in a top-down, chronological sequence.

17. The method of claim **13**, wherein the interactive display of the relationships comprises a nodal diagram illustrating at least the first observed event, the second observed event, and the relationship in a left-to-right, chronological sequence.

18. The computerized method of claim **14**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

19. A system for cyber-attack detection comprising:

one or more hardware processors; and

a non-transitory storage module communicatively coupled to the one or more processors, the storage module comprises

(i) an event log to receive and store a first set of information associated with a plurality of observed events and one or more relationships that identify an association between different observed events, each of the observed events being observed during operation of a source device communicatively coupled to the system, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

(ii) a machine learning data store to store one or more reference models,

(iii) a machine learning logic that, upon execution by the one or more processors,

(a) accesses the first set of information associated with the plurality of observed events, and

(b) enhances a first reference model of the one or more reference models by adding a first event or a first relationship to the first reference model based on a correlation between the first reference model and the first set of information, the first event and the first relationship included in the first set of information, wherein a combination of events and relationships comprising the first reference model indicates a cyber-attack,

(c) generates display screen information including a comparison of the first set of information and the first reference model that includes the first event or the first relationship; and

(iv) a display generation logic that, upon execution by the one or more processors,

(a) communicates with the machine learning logic, and

(b) generates an interactive display screen from the display screen information including at least the first event or the first relationship.

20. The system of claim **17**, wherein the first set of information includes at least two of (i) observations uncovered after virtual processing of a portion of network traffic under analysis by a virtual execution environment, (ii) observations uncovered after static processing of the portion of network traffic by a static analysis engine, and (iii) observations uncovered from monitored network traffic.

21. The system of claim **17**, wherein enhancing the first reference model is performed when the third event and the second relationship were not previously present in the first reference model.

22. The system of claim **17**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

23. A computerized method for malware detection comprising:

accessing a first set of information that comprises (i) information directed to a plurality of observed events, each of the observed events being observed during operation of a source device communicatively coupled to the system, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

generating a reference model based on the first set of information, the reference model comprises at least a first observed event, a second observed event, and a first relationship that identifies that the second observed event is based on the first observed event, wherein the first observed event and the second observed event are included in the plurality of observed events, analyzing a second set of information that is different than the first set of information, the second set of information including a third event and a second relationship,

enhancing the reference model by adding the third event or the second relationship to the reference model based on a correlation between the reference model and the second set of information, and

generating an interactive graphical display of at least the reference model that includes the third event or the second relationship,

wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

24. The method of claim **23**, wherein the anomalous behavior includes a first file opened by a first process, wherein the first file is configured to be opened by a second process that is different from the first process and is not configured to be opened by the first process.

25. The method of claim **23**, wherein the generating of the reference model by the logic comprises determining that the first event of the plurality of observed events performed at least one of an action or an operation, the at least one of the action or the operation results in an observance of subsequent events of the plurality of observed events including the second event of the plurality of observed events.

26. A non-transitory computer readable medium, when processed by a hardware processor, determines whether a first set of information indicates a presence of a cyber-attack, the non-transitory computer readable medium comprising:

a machine learning logic to:

(a) access a first set of information that comprises (i) information directed to a plurality of observed events, each of the observed events being observed during operation of a source device communicatively coupled to the system, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

(b) generate a reference model based on the first set of information, the reference model comprises at least a first observed event, a second observed event, and a first relationship that identifies that the second observed event is based on the first observed event, wherein the first observed event and the second observed event are included in the plurality of observed events,

(c) analyze a second set of information that is different than the first set of information, the second set of information including a third event and a second relationship, and

(d) enhance the reference model by adding the third event or the second relationship to the reference model based on a correlation between the reference model and the second set of information; and

a display generation logic to generate an interactive graphical display of at least the reference model that includes the third event or the second relationship, wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

27. The non-transitory computer readable medium of claim **26**, wherein the anomalous behavior includes a first file opened by a first process, wherein the first file is configured to be opened by a second process that is different from the first process and is not configured to be opened by the first process.

28. The non-transitory computer readable medium of claim **26**, wherein the generating of the reference model by the logic comprises determining that the first event of the plurality of observed events performed at least one of an action or an operation, the at least one of the action or the operation results in an observance of subsequent events of the plurality of observed events including the second event of the plurality of observed events.

29. A computerized method for malware detection comprising:

accessing a first set of information that comprises (i) information directed to a first plurality of observed events stored in a storage module, each of a first plurality of observed events being observed during operation of a source device, the storage module including an event log to store the information associated with at least the first plurality of observed events, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection, that occurs during computer processing, between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code;

accessing a reference model based on a second plurality of observed events, the reference model comprises at least a first observed event of the second plurality of observed events, a second observed event of the second plurality of observed events, and a first relationship that identifies that the second event is based on the first event, wherein the first observed event and the second observed event are included in the plurality of observed events;

enhancing the reference model by adding a third event or a second relationship to the reference model based on a correlation between the reference model and the first set of information, the third event and the second relationship included in the first set of information; and

generating a graphical, interactive display of a comparison of the first plurality of observed events with the reference model that includes the third event of the second relationship, the interactive display including one or more diagrams, wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

30. The method of claim **29**, wherein a first event of the first plurality of observed events is selectable to (i) provide metadata associated with the first event of the first plurality of observed events; (ii) generate a signature of the first event of the first plurality of observed events; or (iii) generate an alert for the first event of the first plurality of observed events.

31. The method of claim **30**, wherein at least the first event and a second event of the first plurality of observed events are selectable via the graphical interactive display.

32. The method of claim **29**, wherein the plurality of diagrams include two or more nodal diagrams placed in a side-by-side manner, the nodal diagrams illustrating (i) each event of the first plurality of observed events and each relationship of the first plurality of observed events and (ii) the reference model.

33. The method of claim **29**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a solid line, the solid line representing that the first event of the first plurality of observed events was observed with at least a first confidence.

34. The method of claim **33**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first event of the first plurality of observed events was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

35. The method of claim **29**, wherein the first relationship is illustrated in the one or more diagrams with a solid line, the solid line representing that the first relationship was observed with at least a first confidence.

36. The method of claim **29**, wherein the first relationship is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first relationship was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

37. A non-transitory computer readable medium, when processed by a hardware processor, determines whether a first set of information indicates a presence of a cyber-attack, the non-transitory computer readable medium comprising:

an event log to store information associated with at least a first plurality of observed events;

logic that:

(a) accesses a first set of information that comprises (i) information directed to the first plurality of observed events stored in the event log, each of the first plurality of observed events being observed during operation of a source device, and (ii) information directed to one or more relationships that identify an association between different observed events, wherein each of the one or more relationships comprises a connection, that occurs during computer processing, between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code,

(b) accesses a reference model based on a second plurality of observed events, the reference model comprises at least a first observed event of the second plurality of observed events, a second observed event of the second plurality of observed events, and a first relationship that identifies that the second event is based on the first event, wherein the first observed event and the second observed event are included in the plurality of observed events, and

(c) enhances the reference model by adding a third event or a second relationship to the reference model based on a correlation between the reference model and the first set of information, the third event and the second relationship included in the first set of information; and

a display generation logic to generate a graphical, interactive display of a comparison of the first plurality of observed events with the reference model that includes the third event of the second relationship, the interactive display including one or more diagrams, wherein a combination of events and relationships comprising the reference model indicate a cyber-attack.

38. The non-transitory computer readable medium of claim **37**, wherein a first event of the first plurality of observed events is selectable to (i) provide metadata associated with the first event of the first plurality of observed events; (ii) generate a signature of the first event of the first plurality of observed events; or (iii) generate an alert for the first event of the first plurality of observed events.

39. The non-transitory computer readable medium of claim **37**, wherein at least the first event and a second event of the first plurality of observed events are selectable via the graphical interactive display.

40. The non-transitory computer readable medium of claim **37**, wherein the plurality of diagrams include two or more nodal diagrams placed in a side-by-side manner, the nodal diagrams illustrating (i) each event of the first plurality of observed events and each relationship of the first plurality of observed events and (ii) the reference model.

41. The non-transitory computer readable medium of claim **37**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a solid line, the solid line representing that the first event of the first plurality of observed events was observed with at least a first confidence.

42. The non-transitory computer readable medium of claim **41**, wherein the first event of the first plurality of observed events is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first event of the first plurality of observed events was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

43. The non-transitory computer readable medium of claim **37**, wherein the first relationship is illustrated in the one or more diagrams with a solid line, the solid line representing that the first relationship was observed with at least a first confidence.

44. The non-transitory computer readable medium of claim **37**, wherein the first relationship is illustrated in the one or more diagrams with a dotted line, the dotted line representing that the first relationship was observed with at least a second confidence but less than a first confidence, the first confidence being greater than the second confidence.

45. A computerized method for malware detection comprising:

receiving and storing, by an event log, a first set of information associated with a plurality of observed events and one or more relationships that identify an association between different observed events, each of the observed events being observed during operation of a source device, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code;

accessing, by a machine learning logic, the first set of information associated with the plurality of observed events;

enhancing, by a machine learning logic, a first reference model of one or more stored reference models by adding a first event or a first relationship to the first reference model based on a correlation between the first reference model and the first set of information, the first event and the first relationship included in the first set of information, wherein the one or more reference models including the first reference model are stored in a machine learning data store, wherein a combination of events and relationships comprising the first reference model indicates a cyber-attack;

generating, by a machine learning logic, display screen information including a comparison of the first set of information and the first reference model that includes the first event or the first relationship;

communicating, by a display generation logic, with the machine learning logic; and

- generating, by the display generation logic, an interactive display screen from the display screen information including at least the first event or the first relationship.

46. The computerized method of claim **45**, wherein the first set of information includes at least two of (i) observations uncovered after virtual processing of a portion of network traffic under analysis by a virtual execution environment, (ii) observations uncovered after static processing of the portion of network traffic by a static analysis engine, and (iii) observations uncovered from monitored network traffic.

47. The computerized method of claim **45**, wherein enhancing the first reference model is performed when the third event and the second relationship were not previously present in the first reference model.

48. The computerized method of claim **45**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

49. A non-transitory computer readable medium, when processed by a hardware processor, determines whether a first set of information indicates a presence of a cyber-attack, the non-transitory computer readable medium comprising:

- an event log to receive and store a first set of information associated with a plurality of observed events and one or more relationships that identify an association between different observed events, each of the observed events being observed during operation of a source device, wherein each of the one or more relationships comprises a connection that occurs during computer processing between at least two events and wherein each of the plurality of observed events is an action or operation resulting from an execution of code;
- a machine learning data store to store one or more reference models;

- a machine learning logic to (a) access the information associated with the plurality of observed events, and (b) enhance a first reference model of the one or more reference models by adding a first event or a first relationship to the first reference model based on a correlation between the first reference model and the first set of information, the first event and the first relationship included in the first set of information, wherein a combination of events and relationships comprising the first reference model indicates a cyber-attack, (c) generate display screen information including a comparison of the first set of information and the first reference model that includes the third event or the second relationship; and
- a display generation logic to (a) communicate with the machine learning logic, and (b) generate an interactive display screen from the display screen information, including the first event or the first relationship .

50. The non-transitory computer readable medium of claim **49**, wherein the first set of information includes at least two of (i) observations uncovered after virtual processing of a portion of network traffic under analysis by a virtual execution environment, (ii) observations uncovered after static processing of the portion of network traffic by a static analysis engine, and (iii) observations uncovered from monitored network traffic.

51. The non-transitory computer readable medium of claim **50**, wherein enhancing the first reference model is performed when the third event and the second relationship were not previously present in the first reference model.

52. The non-transitory computer readable medium of claim **51**, wherein the source device is one of an endpoint device, a threat detection system, or a cloud computing service.

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